August 2018

Comparison of Analysis Techniques for Assessing Oro-Pharyngeal Swallow from Videofluoroscopy

Prasanna Venkataraman
University of Wisconsin-Milwaukee

COMPARISON OF ANALYSIS TECHNIQUES FOR ASSESSING ORO-PHARYNGEAL SWALLOW FROM VIDEOFLUOROSCOPY

by

Prasanna Venkataraman

A Thesis Submitted in

Partial Fulfilment of the

Requirements for the Degree of

Master of Science

in Communication Sciences and Disorders

at

The University of Wisconsin-Milwaukee

August 2018

ABSTRACT

COMPARISON OF ANALYSIS TECHNIQUES FOR ASSESSING ORO-PHARYNGEAL SWALLOW FROM VIDEOFLUOROSCOPY

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The University of Wisconsin-Milwaukee, 2018
Under the Supervision of Professor Barbara Pauloski

MBSImP® is an ordinal rating scale designed to evaluate 17 swallowing events from Videofluoroscopic Swallowing Study. Use of an ordinal scale to judge swallowing impairment involves subjectivity and could affect the reliability of judgements. There is a need to validate the ordinal levels of ratings in MBSImP® with objective data, in order to improve confidence of clinical judgements. The hypothesis was that discrete objective data could be obtained for each level of rating in MBSImP® that are statistically different from the data of the subsequent rating level, which would objectively support the concept of the MBSImP® tool. Two hundred 5ml thin liquids swallows were analyzed and each swallow was rated for MBSImP® Component 9- Anterior Hyoid Excursion. As the corresponding objective measure, the anterior excursion of the hyoid in normalized scalar units was measured for each swallow using ImageJ. Statistical analysis of the data with a one way ANOVA revealed a statistically significant difference ($p<0.001$) in the mean of anterior hyoid excursion in normalized scalar units among the MBSImP® ratings levels with R^2 value of 0.20. Multiple paired comparisons performed using Bonferroni adjustment in SPSS revealed significant differences among all ratings levels. The study aimed to find if quantifiable data could be applied to different levels ratings of MBSImP® components. As expected, there was a decrease in the mean anterior hyoid excursion in normalized scalar units as the level of MBSImP® rating increased for Component 9. However, the R^2 value of the ANOVA revealed that only 20% of the variation in the objective data of anterior hyoid excursion in normalized scalar units could be explained by different levels of rating on the component of interest of MBSImP® tool. Though this study could not satisfactorily prove the concept of the tool, the objective data of anterior hyoid excursion in normalized scalar units categorized by rating levels of MBSImP® show the potential to achieve this in the future.

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ACKNOWLEDGEMENTS

Foremost, I thank the almighty for blessing my life with my lovely grandmother. Being brought up by her is the biggest fortune I have had in my life. Thank you Paatti for all the unconditional love. Every accomplishment in my life, starting from the first step I took as a kid to what I will achieve in the future is because of you.

I would like to thank my thesis mentor Dr. Barbara Pauloski for all her patience and support throughout this thesis. Words cannot fully describe my gratitude to Dr. Pauloski for believing in my research potential, appreciating my interest in dysphagia, helping me propose my thesis topic, supporting my application for thesis grants, steering me in the right direction during the course of the study and assisting me massively to write this paper. I am fortunate beyond measure to have had this opportunity to work with her.

Besides my thesis mentor, I would like to thank Dr. Marylou Gelfer for being a wonderful faculty advisor, agreeing to serve on my thesis committee and supporting my applications for Chancellor's Graduate Student Award and other scholarships which eased my financial burden during my master's program. My sincere thanks to Dr. Sabine Heuer for agreeing to serve on my thesis committee and for her valuable inputs to the study. I am grateful to Mr. Chris Cho for helping me with the statistical analysis for the study. In addition, I would like to thank my classmates Heather Christensen, Laura Ehlen, and Madison Meier for their contributions to establishing inter-rater reliability for this study.

I sincerely thank Dr. Abigail Amissah-Arthur and UWM College of Health Sciences Research Growth Committee for supporting my thesis with Student Research Grant Award. I thank Dr. Caryn Easterling for appreciating my background, career interests and financial needs by conferring the Friends of WSHA Scholarship on me. For her timely motivation, I also would like to thank my internship supervisor Mrs. Jacqueline Saunders.

I also would like to express my gratitude to my caring brothers Vimal and Shabeer for their enormous contribution to my life. Special thanks to my lovely sister-in-law Kavitha. I also would like to thank my friends Yamunai, Darshit, Jackson & Jeny. Without you all, I wouldn't have reached here.

I owe every bit of my success to my family, especially my father. Thank you Appa for moulding me into the person I am today. You are the best teacher I have had. Thank you Amma for all your sincere prayers for me. I would like to thank my parents-in-law for all their support. I thank my siblings Krishna and Preethi. I extend my gratitude to Giri Athimber and my nephew Arjun. A big panda hug to my dog Jaambu for being there for my wife when I could not in these two years.

Finally, I would like to thank the lovely woman to whom I would like to dedicate this work. My best friend and wife, Priya. Thank you for always believing in me and silently enduring for my success. You are an ideal to the quote, "Behind every successful man, there is a woman." In this life, if I manage to give you half the things you have given me so far, I will be the best husband ever. Thank you de!

COMPARISON OF ANALYSIS TECHNIQUES FOR ASSESSING ORO-PHARYNGEAL SWALLOW FROM VIDEOFLUOROSCOPY.

Introduction

Dysphagia

Dysphagia is defined as difficulty in swallowing. According to a 2012 National Institutes of Health interview survey, an estimated 9-10 million adults reported dysphagia in the United States while 1 in 25 adults acquire dysphagia every year (Bhattacharya, 2014). Dysphagia is caused by conditions that affect the physiology of the head and neck musculature (Groher & Crary, 2016). It is found in 51-55% of stroke survivors on clinical examination and in 64-78% on instrumental evaluations (Martino et al., 2005); 30-50% of head and neck cancer patients following radiotherapy (Schindler et al., 2015) and 50.6% of head & cancer patients at 28 months post-surgery (Garcia-Peris et al., 2007).

Normal swallowing occurs through series of events through different stages, namely, oral preparatory, oral, pharyngeal, and esophageal. Dysphagia may occur at any or multiple stages (Logemann, 1984). Aspiration refers to entry of foreign material into the airway below the level of the true vocal folds; it can potentially cause pulmonary infection, aspiration pneumonia, malnutrition or dehydration (Sura, Madhavan, Carnaby & Crary 2012; Rofes et al., 2011). There is a relationship between oro-pharyngeal dysphagia leading to aspiration of the bolus and aspiration pneumonia (Langmore et al., 1998). The presence of oro-pharyngeal dysphagia can lead to increased risk of infections being acquired during stays in the hospitals, longer length of stays in hospitals, longer time to achieve clinical stability (Wirth et al., 2016), and readmission to hospitals due to pneumonia (Cabre et al., 2014). In the elderly, aspiration pneumonia may be life threatening and has been identified as a cause of mortality (Wirth et al., 2016). To prevent the consequences of aspiration pneumonia, dysphagia is ideally assessed and managed by Speech Language Pathologists beginning at the acute phase.

Swallowing Assessment

Swallowing assessments are usually done clinically and supplemented with findings of an instrumental swallowing evaluation using either a Videofluoroscopic Swallowing Study (VFSS) or Fiberoptic Endoscopic Examination of Swallowing (FEES) (Groher & Crary, 2016). Both instrumental evaluation examinations have high levels of agreement in detecting risk of aspiration (Langmore, 2003). There is evidence that a high proportion of clinicians perform an instrumental swallowing evaluation after a clinical bedside evaluation before initiating dysphagia management, as imaging helps clinicians in planning their intervention (Groher & Crary, 2016).

Videofluoroscopic Swallowing Study (VFSS)

Videofluoroscopic swallow study (VFSS), also known as the Modified Barium Swallow (MBS), is a swallow imaging technique usually performed by Speech Language Pathologists in collaboration with Radiologists (Gates, Hartnell & Gramigna, 2006). It is the preferred procedure by most clinicians and evidence shows that at least 60% of clinicians routinely complete VFSS before initiating their intervention for dysphagia to have a clearer idea of contributing swallowing physiology or pathophysiology (Groher & Crary, 2016). The VFSS procedure uses video-recorded fluoroscopy to examine swallow physiology comprehensively from the lips to esophagus in response to trials with various bolus volumes (e.g., 3 ml, 5 ml, 10 ml, 30 ml, self-selected cup drinking), viscosities (e.g., thin liquid, nectar thickened liquid) and textures (e.g., pudding, cookie, sliced banana) in the lateral and anterior-posterior planes (Gates et al., 2006). The sequential images obtained in the VFSS are then interpreted by Speech Language Pathologists (SLP), sometimes in collaboration with the radiologist, for swallowing safety and efficiency (Martin-Harris & Jones, 2008).

Fiberoptic Endoscopic Evaluation of Swallowing (FEES)

Fiberoptic Endoscopic Evaluation of Swallowing (FEES) uses an endoscope, which is a thin, flexible tube with a camera and white light on one end to image swallowing. The endoscope is attached to a computer and recording system for playback and analysis purposes. After application of necessary topical anesthetics to the nasal cavity, the endoscope is inserted into the nostril through the nasal cavity and into the oro-pharynx to be positioned at the level of the supraglottis to view the pharyngeal structures during swallowing. FEES is the first choice of instrumental evaluation in clinical situations of difficulty in transferring individuals needing assessments, need to do assessments in intensive care units, need to do assessments in individuals with quadriplegia or severe hemiplegia, concern about excessive radiation exposure, need for a therapeutic tool for biofeedback during dysphagia intervention, or need for assessment of secretion management/dysphonia/breathing-swallowing coordination (Kidder, Langmore & Martin, 1994).

Though both VFSS and FEES have high value as instrumental assessment tools, VFSS has often been cited as the gold standard for instrumental evaluation of swallowing (Costa, 2010). VFSS is seen as gold standard because of its potential to assess overlapping and interdependent structural movements during swallowing, which is not possible with FEES due to supraglottic positioning of the endoscope (Martin-Harris & Jones, 2008). VFSS is an ideal tool as it allows clinicians to observe movements of structures at the level of oral cavity, pharynx and esophagus while swallowing, as well as observation of incidences of penetration and aspiration of the bolus. Due to the moment of whiteout during initiation of the pharyngeal phase of swallowing, FEES does not provide comprehensive information on the pharyngeal phase (Kidder et al, 1994) along with limited or no information on the esophageal phase of swallowing. FEES also includes the possible risk of discomfort, gagging/vomiting, epistaxis, mucosal perforation, adverse reaction to topical anesthetics and laryngospasm (Nacci et al., 2008).

However, use of VFSS as an instrumental evaluation procedure by SLPs has long been criticized for lack of standardized assessment protocols, interpretation methods, interpretation terminologies and reporting of results (Groher & Crary, 2016; Martin-Harris & Jones, 2008; Langmore, 2003; O'Donoghue & Bagnall, 1999). Lack of standardization of an assessment protocol also leads to prolonged radiation exposure (Bonilha et al., 2013). Poor inter-judge reliability of the judgment of the outcomes as observed in VFSS also has been discussed and reported in the literature (Baijens, Barikroo & Pilz, 2013; Bryant, Finnegan & Berbaum, 2012; Langmore, 2003; Stoeckli, Huisman, Seifert & Martin-Harris, 2003; McCullough et al., 2001). This lack of standardization affects understanding of the outcomes of dysphagia management and the efficacy of various treatment options available in the literature (Martin-Harris & Jones, 2008).

Subjectivity in VFSS assessment protocol and interpretation terminologies has raised the need for standardization of the procedure for assessing and quantifying oro-pharyngeal dysphagia (Martin-Harris & Jones, 2008). With a standardized protocol, interpretation methods and language of reporting, VFSS would provide invaluable information on the physiology or pathophysiology of swallowing with limited radiation exposure, which could be easily communicated across settings and reported in the dysphagia literature with a language that is universally understood by fellow professionals. Such standardization would aid better understanding and comparisons of the outcomes of different dysphagia management approaches and improve evidence-based practice in the field of dysphagia (Martin-Harris et al., 2008).

Modified Barium Swallow Impairment Profile (MBSImP®)

To address the lack of standardization in VFSS affecting its clinical utility in terms of assessment protocol, interpretation and reporting, a standardized assessment procedure, the MBSImP® was developed by Martin-Harris et al. (2008). MBSImP® was designed to evaluate 17 important swallowing temporal and biomechanical events from VFSS including lip seal, tongue control during bolus hold, bolus preparation/mastication, bolus transport, oral residue, initiation of pharyngeal swallow, soft palate elevation, laryngeal elevation, anterior hyoid excursion, epiglottic movement, laryngeal vestibular closure, pharyngeal stripping wave, pharyngeal contraction, pharyngeo-esophageal segment opening, tongue base retraction, pharyngeal residue and esophageal clearance (Martin-Harris et al., 2008). MBSImP® has been standardized on a large clinical population and has been found to be highly valid and reliable (Martin-Harris et al., 2008).

MBSImP® uses an ordinal scale for rating the degree of severity of impairment of the 17 swallowing events (Martin-Harris et al., 2008). Extensive efforts have been taken to standardize the tool with dedicated training modules and a certification process before using the tool clinically to ensure reliability. However, using an ordinal scale to judge swallowing impairment involves subjectivity and could affect the reliability of judgements across clinicians and settings. Although there are no critiques on the rating scales of the tool available in the literature currently, poorer inter-judge reliability in the scores of MBSImP® when different pulse rates of radiation during MBS has been reported (Bonilha et al., 2013). This subjectivity may impact confidence of clinical judgement of swallowing impairments and treatment recommendations (Bonilha et al., 2013) which could overall influence clinical resources and management of dysphagia.

Hence, there is a need to validate the ordinal levels of ratings in MBSImP® with objective data in order to improve confidence of clinical judgements and recommendations using MBSImP®. This validation could be achieved by attempting to measure and apply quantifiable data to the different levels of ratings in MBSImP® so that a discrete range of objective data may help clinicians in discriminating the different levels of MBSImP® and give them confidence that the subjective measures are supported by objective data.

Temporal and Biomechanical Measures of Swallow

Swallowing is a complex physiologic process that progresses through a sequence of rapid and highly coordinated events, including closure of the velopharyngeal port, anterior and superior hyoid bone excursion, epiglottic retraction, closure of the laryngeal vestibule, tongue base retraction to the posterior pharyngeal wall, progression of pharyngeal wave down the pharynx, and upper esophageal sphincter opening (Dodds, Stewart & Logemann, 1990).

Analysis of oro-pharyngeal swallow from VFSS to measure temporal and biomechanical movements during the swallowing would give objective data on the different swallowing movements through different stages (Logemann et al., 2000). Temporal measures are used to analyze and quantify the event timing and duration aspects of swallowing movements, for example, time taken for mastication, time at which the first movement of the bolus passes the posterior nasal spine that led to a swallow (B1), time at which the head of the bolus first arrived in the valleculae (BV1), the time at which the bolus head first entered the upper esophageal sphincter (BP1), time of the first anterior and/or superior movement of hyoid bone that led to a swallow (H1) (Leonard & McKenzie, 2006).

Biomechanical measures analyze and quantify the extent of displacement of oral and pharyngeal structures during swallowing, for instance, maximum uvular displacement, maximum vertical hyoid displacement, maximum anterior hyoid displacement, extent of epiglottic retraction during laryngeal vestibule closure, extent of tongue base retraction to posterior pharyngeal wall, extent of anterior arytenoid movement (Leonard, Kendall &

McKenzie, 2004; Logemann et al., 2000). Efficiency measures analyze and quantify the efficacy of the movements in swallowing, including percentage of residue in oral cavity, valleculae and pyriform sinus after the first attempt of oral and pharyngeal transit, and the pharyngeal constriction ratio (Stokely, Peladeau-Pigeon, Leigh, Molfenter & Steele, 2015; Leonard, Rees, Belafsky & Allen, 2011).

Swallowtail (Belldev Medical, LLC) is a software platform that is designed for comprehensive VFSS image analysis using built-in analysis tools for determining length of lines, areas of regions of interest, and temporal measures between images. ImageJ is a public domain Java-based image processing program available from the National Institutes of Health (https://imagej.nih.gov/ij/). Both Swallowtail and ImageJ are customizable so the researcher can build tools for a specific research question.

Swallowtail and ImageJ have the potential to produce the above-mentioned objective measures of temporal and biomechanical aspects of swallow from VFSS. Although the objective research data do not have direct clinical applicability, they could be compared to relevant MBSImP® components to determine if quantifiable data could be applied to the ordinal levels of the tool.

With these swallowing assessment and measurement tools, the data analysis of this study aimed to validate the different ordinal rating levels of MBSImP® by supporting the intervals with different ranges of objective data. Hence, the hypothesis was that discrete objective data could be obtained for each level of rating in MBSImP® that are statistically different from the data of the subsequent rating level, which would objectively support the concept of MBSImP® tool. The research questions were:

1. To find how the different VFSS interpretation tools compared, i.e., how the components of MBSImP® compared with objective measures of swallowing obtainable using Swallowtail and ImageJ.

2. To find if quantifiable data could be applied to the use of MBSImP® and thereby, to validate the levels of ratings of MBSImP®.

Methodology

This study was conducted in the Swallow Physiology Laboratory, Department of Communication Sciences and Disorders (CSD), College of Health Sciences (CHS), University of Wisconsin - Milwaukee (UWM). It was conducted by the thesis candidate, Prasanna Venkataraman, in collaboration with three graduate students, Madison Meier (MM), Heather Christensen (HC) and Laura Ehlen (LE), participating in a research experience (COMSDIS 791) as a partial fulfillment of the requirement for the degree of Master of Science in Communication Sciences & Disorders under the supervision of the faculty mentor and thesis advisor, Dr. Barbara Pauloski. The study is a comparison of analysis techniques of oro-pharyngeal swallow from VFSS using MBSImP®, Swallowtail and ImageJ. Figure 1 provides a visual summary of the methodology for this study.

Selection of Study Measures

Interpretation of VFSS using MBSImP®. MBSImP® recommends a 12-swallow protocol that standardizes the bolus preparations and presentations in lateral and anterior-posterior views during the VFSS. This 12-swallow protocol includes: 1) 5 ml thin liquid via teaspoon (to prime the swallowing system; not considered for rating); 2) 5 ml thin liquid via teaspoon; 3) single sip of thin liquid from cup; 4) thin liquid sequential swallow; 5) 5 ml nectar thick liquid via teaspoon; 6) single sip of nectar thick liquid from cup; 7) nectar thick liquid sequential swallow; 8) 5 ml honey thick liquid via teaspoon; 9) 5 ml pudding thick via teaspoon; 10) ½ shortbread cookie in 3 ml of pudding; 11) 5 ml nectar thick liquids via teaspoon (anterior-posterior view); 12) 5 ml pudding thick via teaspoon (anterior-posterior view).

MBSImP© uses an ordinal rating scale to rate swallowing impairment. Since it is likely that swallowing impairment differs between different bolus volumes and consistencies, an overall impression score is assigned to each of the 17 components of swallowing rated using MBSImP® based on the worst score observed across all bolus volumes and consistencies. The 17 components cover the oral phase, pharyngeal phase and esophageal phases of swallowing.

Oral:

1. Lip closure
2. Tongue control during bolus hold
3. Bolus preparation/mastication
4. Bolus transport/lingual motion
5. Oral residue
6. Initiation of pharyngeal swallow

Pharyngeal:

7. Soft palate elevation
8. Laryngeal elevation
9. Anterior hyoid excursion
10. Epiglottic movement
11. Laryngeal vestibular closure-height of swallow
12. Pharyngeal stripping wave
13. Pharyngeal contraction
14. Pharyngeo-esophageal segment opening
15. Tongue base retraction
16. Pharyngeal residue

Esophageal:

17. Esophageal clearance upright position.

An evaluation of all 17 components was deemed beyond the scope of this thesis. A limited set of components was selected in order to represent key aspects of the oral and pharyngeal stages of the swallow. Consideration was given to those components that had a logical relationship with published temporal and biomechanical measures of the oropharyngeal swallow. In addition, some components were eliminated on the following basis:

1) Because the MBSImP® protocol is not yet widely utilized, most of the VFSS in the UWM database were not performed using the MBSImP® protocol. Therefore, some aspects of the MBSImP® analysis, e.g. Esophageal Component and Pharyngeal Contraction in the AP view, could not be measured.
2) The faculty mentor’s preliminary review of the database revealed few examples of poor lip closure and velopharyngeal incompetency, so Component 1, Lip Closure and Component 7, Soft palate elevation, were eliminated from consideration.

The final set of components chosen for evaluation in this study were:

Component 6. Initiation of pharyngeal swallow

Component 8. Laryngeal elevation

Component 9. Anterior hyoid excursion

Component 14. Pharyngeal esophageal segment opening

Component 15. Tongue base retraction

Temporal and Biomechanical Measures of Swallow using Swallowtail and ImageJ. Five displacement measures were proposed for comparison with MBSImP® components of interest: 1. maximum vertical larynx displacement at first closure of laryngeal vestibule, 2. maximum anterior hyoid displacement, 3. extent of anterior arytenoid movement at first closure of laryngeal vestibule, 4. extent of tongue base retraction to posterior pharyngeal wall, and 5. width of maximum cricopharyngeal opening.

Vertical larynx displacement at first closure of laryngeal vestibule was measured by the difference in the distance between anterior tip of thyroid notch or laryngeal prominence and anterior-inferior tip of C4 at rest and when the epiglottis is horizontal in position to close the laryngeal vestibule during swallowing. *Maximum anterior hyoid displacement* was measured by the difference in the distance between anterior-inferior tip of hyoid bone and anterior-inferior tip of C2 at rest and at maximum displacement during swallowing (Pauloski, Logemann, Fox & Colangelo, 1995).

A line from the anterior-superior tip of the arytenoid to the point on the posterior surface of the epiglottic base immediately anterior to the arytenoid to represent laryngeal closure at the vestibule gave the *extent of anterior arytenoid movement at first closure of laryngeal vestibule* (Pauloski et al., 1995).

Extent of tongue base retraction to posterior pharyngeal wall was obtained by 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 anterior movement of the posterior pharyngeal wall (Pauloski et al., 1995). *Width of maximum cricopharyngeal opening* was calculated by the distance between anterior and posterior tips of the pharyngeo-esophageal segment (PES) during maximum PES opening at the level of C4. (Leonard et al., 2004).

Two temporal measures were to be assessed in the study for comparison with MBSImP® components of interest: 1. *onset of hyoid movement relative to onset of oral transit* (adapted from Kendall & Leonard, 2001) and 2. *duration of maximum cricopharyngeal opening* (Kendall & Leonard, 2001). Table 1 summarizes the Temporal and Biomechanical Measures proposed for the study.

Table 1: Temporal and Biomechanical measures of swallow proposed for the study.

Swallowtail and ImageJ measure	Definition	Measure type	Unit
Onset hyoid movement relative to onset of oral transit	The time at which there is first anterior/superior movement of hyoid bone that leads to a swallow.	Temporal: Event timing	s
Vertical larynx displacement at first closure of laryngeal vestibule:	Measured by the difference in the distance between anterior tip of thyroid notch or laryngeal prominence relative to anchor point- anterior inferior tip of C4 at rest and when the epiglottis is horizontal in position during swallowing.	Displacement	mm
Maximum anterior hyoid displacement	Measured by the difference in the distance between anterior-inferior tip of hyoid bone relative to anchor point- anterior inferior tip of C4 at rest and at maximum displacement during swallowing.	Displacement	mm
Extent of anterior arytenoid movement at first closure of laryngeal vestibule.	Measured by a line from anterior-superior tip of arytenoid to the point on the posterior surface of the epiglottic base immediately anterior to the arytenoid to represent laryngeal closure at the vestibule.	Displacement	mm
Width of maximum pharyngo-esophageal opening.	The maximum distance between anterior and posterior tips of PES during maximum PES opening.	Displacement	mm
Duration of maximum cricopharyngeal opening.	Duration of maximum PES opening during swallowing.	Temporal	s
Extent of posterior tongue base movement.	Measured by a line from the anterior-inferior corner of C2 to a point on posterior pharyngeal wall and a point on the tongue base at that level.	Displacement	mm

Comparison of MBSImP® and Temporal/Biomechanical Measures of Swallow using Swallowtail and ImageJ. Five MBSImP® components were selected for comparison to objective (temporal and biomechanical) measures obtained from Swallowtail and ImageJ. Table 2 shows the MBSImP® components and their comparable Temporal and Biomechanical measures of swallow selected for the study to answer the research questions.

Table 2: MBSImP® components and comparable objective measures.

MBSImP® Component and rating levels	Objective Measures	Rationale
6. Initiation of pharyngeal swallow 0 = Bolus head at posterior angle of ramus (first hyoid excursion) 1 = Bolus head in valleculae 2 = Bolus head at posterior laryngeal surface of epiglottis 3 = Bolus head in pyriforms 4 = No visible initiation at any location	Onset hyoid movement relative to onset of oral transit	This component of MBSImP® is rated based on how delayed is the first brisk movement of superior-anterior hyoid trajectory with respect to bolus position in the pharynx. This is relatable to H1 as it measures the time at which the initial movement of hyoid bone is seen in response to pharyngeal swallow.
8. Laryngeal elevation 0 = Complete superior movement of thyroid cartilage with complete approximation of arytenoids to epiglottic petiole 1 = Partial superior movement of thyroid cartilage/partial approximation of arytenoids to epiglottic petiole 2 = Minimal superior movement of thyroid cartilage with minimal approximation of arytenoids to epiglottic petiole 3 = No superior movement of thyroid cartilage	Vertical larynx displacement at first closure of laryngeal vestibule Extent of anterior arytenoid movement. at first closure of laryngeal vestibule	This component of MBSImP® judges the laryngeal elevation during initial elevation of the larynx and at the time of first closure of the laryngeal vestibule, i.e., when the body of the epiglottis is in the horizontal position. The same structural movements will be objectively measured at first closure of laryngeal vestibule.
9. Anterior hyoid excursion 0 = Complete anterior movement 1 = Partial anterior movement 2 = No anterior movement	Maximum anterior hyoid displacement	The structural movement rated in this MBSImP® component is directly relatable to our objective measure.
14. PES Opening 0 = Complete distension and complete duration; no obstruction of flow 1 = Partial distension/partial duration; partial obstruction of flow 2 = Minimal distension/minimal duration; marked obstruction of flow	Width of maximum crico-pharyngeal opening Duration of crico-pharyngeal opening	The structural movement and duration rated in this MBSImP® component are directly relatable to our objective measures.

3 = No distension with total obstruction of flow		
15. Tongue base retraction 0 = No contrast between TB and posterior pharyngeal wall (PW) 1 = Trace column of contrast or air between TB and PW 2 = Narrow column of contrast or air between TB and PW 3 = Wide column of contrast or air between TB and PW 4 = No visible posterior motion of TB	Extent of posterior tongue base movement Extent of anterior movement of posterior pharyngeal wall.	The structural movement rated in this MBSImP® component is directly relatable to our objective measure.

Training in Study Procedures

MBSImP® is intended to be used for clinical purposes after the user completes an online training program. After the online training, trainees are expected to meet the reliability standard of 80% agreement on each component before they can be listed as certified users of the MBSImP® tool (Northern Speech Services, 2017). The thesis candidate, a research experience graduate student (MM), and the faculty mentor participated in the online training program before using the MBSImP® tool for data analysis in this study, focusing on the five components that were selected for analysis. The thesis candidate and research experience student (MM) were to reach 90% agreement on training swallows before proceeding to analysis of study data.

ImageJ is a public domain Java-based image processing program available from the National Institutes of Health (https://imagej.nih.gov/ij/). Extensive documentation on the use of ImageJ is available at the NIH website. In addition, the faculty mentor trained the thesis candidate and two research experience graduate students in the specific ImageJ procedures used in the Swallow Physiology Laboratory. ImageJ was used to make measurements of swallow biomechanics for this study. The thesis candidate and research experience students (HC & LE) were to reach an inter-rater reliability of at least r=.90 on training swallows before proceeding to analysis of study data.

Swallowtail was procured from Belldev Medical and installed in the Swallow Physiology Laboratory. Belldev Medical provided several training sessions for the thesis candidate, faculty mentor and research experience graduate students in the use and capabilities of Swallowtail. Swallowtail was to be used to make temporal measures of the swallow. The thesis candidate and research experience students (HC & LE) were to reach an inter-rater reliability of at least r=.90 on training swallows before proceeding to analysis of study data.

De-identified VFSS samples from the UWM Swallow Physiology Laboratory database were available for training and analysis in the study. The VFSS study samples were screened by the faculty mentor for adequate frame rate, image clarity, and visualization of oral and pharyngeal structures during swallowing. Twenty samples were selected for initial training of all student researchers. A second set of twenty training samples was available for additional practice as needed to achieve target reliability levels.

Figure 1: Rest frame from VFSS sample used for practice in the study. 1. Anterior-inferior tip of C2, 2. Anterior inferior tip of C4, 3. Anterior-inferior tip of hyoid bone, 4. Anterior-inferior tip of thyroid cartilage, 5. Distance between anterior-superior tip of arytenoid cartilage and epiglottis, 6. Closed PES at rest, 7. Distance between posterior pharyngeal wall and base of the tongue at the level of anterior-inferior tip of C2

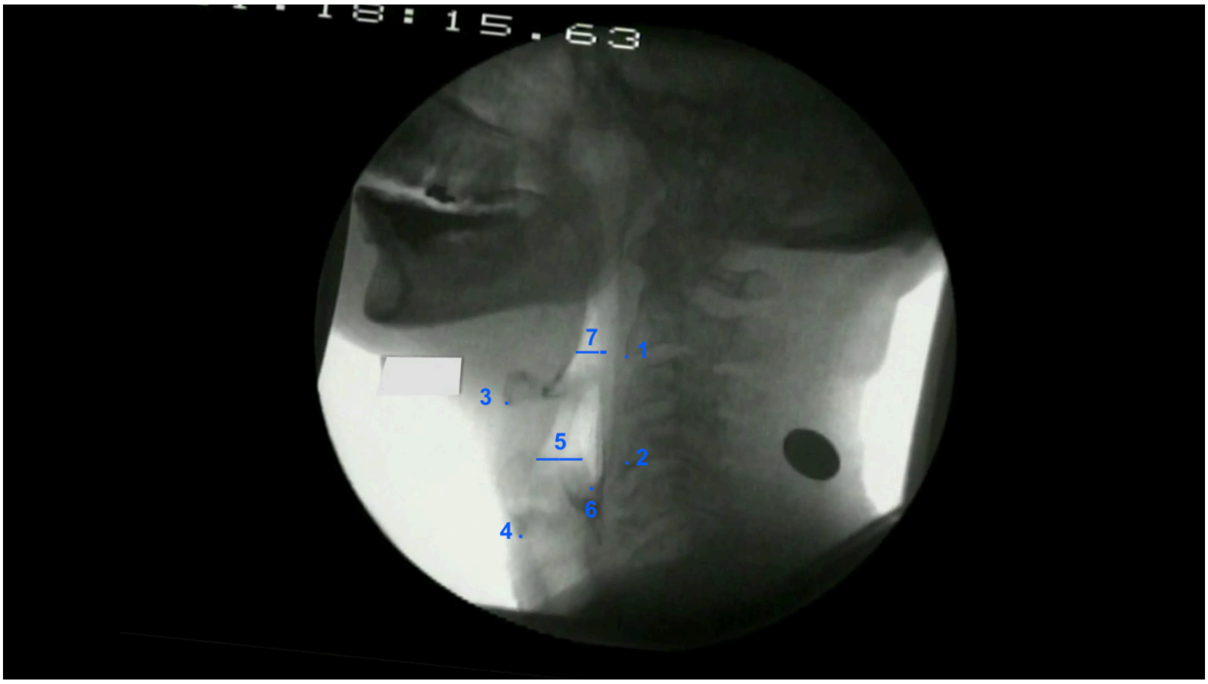


Figure 2: Frame of first laryngeal closure during swallowing from VFSS sample used for practice in the study. 1. Anterior-inferior tip of C2, 2. Anterior inferior tip of C4, 3. Anterior-inferior tip of thyroid cartilage, 4. Distance between anterior-superior tip of arytenoid cartilage and epiglottis.

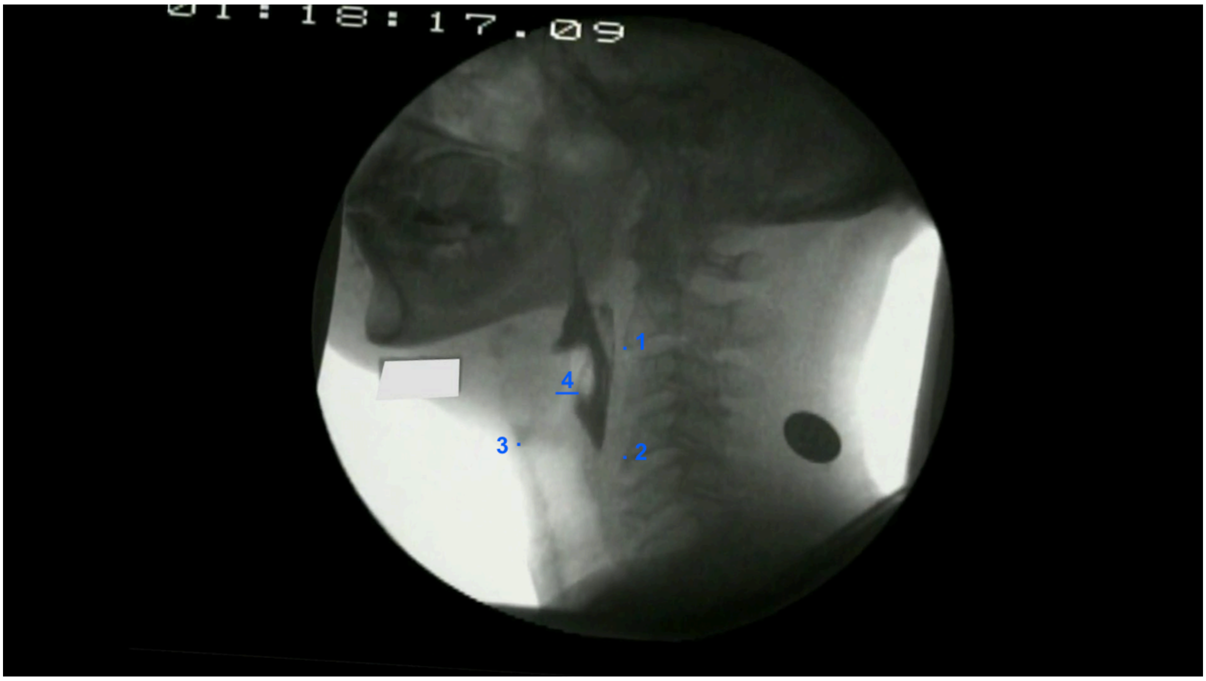


Figure 3: Frame of maximum hyoid excursion during swallowing from VFSS sample used for practice in the study. 1. Anterior-inferior tip of C2, 2. Anterior inferior tip of C4, 3. Anterior-inferior tip of hyoid bone.

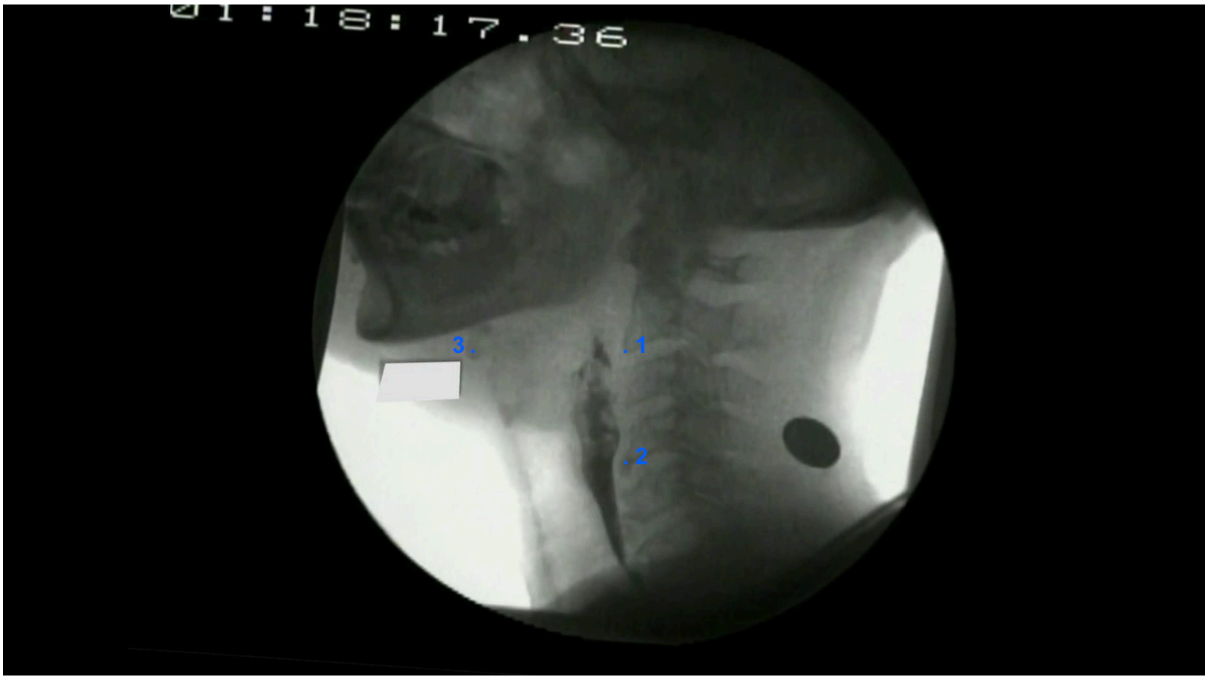


Figure 4: Frame of maximum tongue base retraction during swallowing from VFSS sample used for practice in the study. 1. Anterior-inferior tip of C2, 2. Anterior inferior tip of C4, 3. Distance between posterior pharyngeal wall and base of the tongue at the level of anterior-inferior tip of C2.

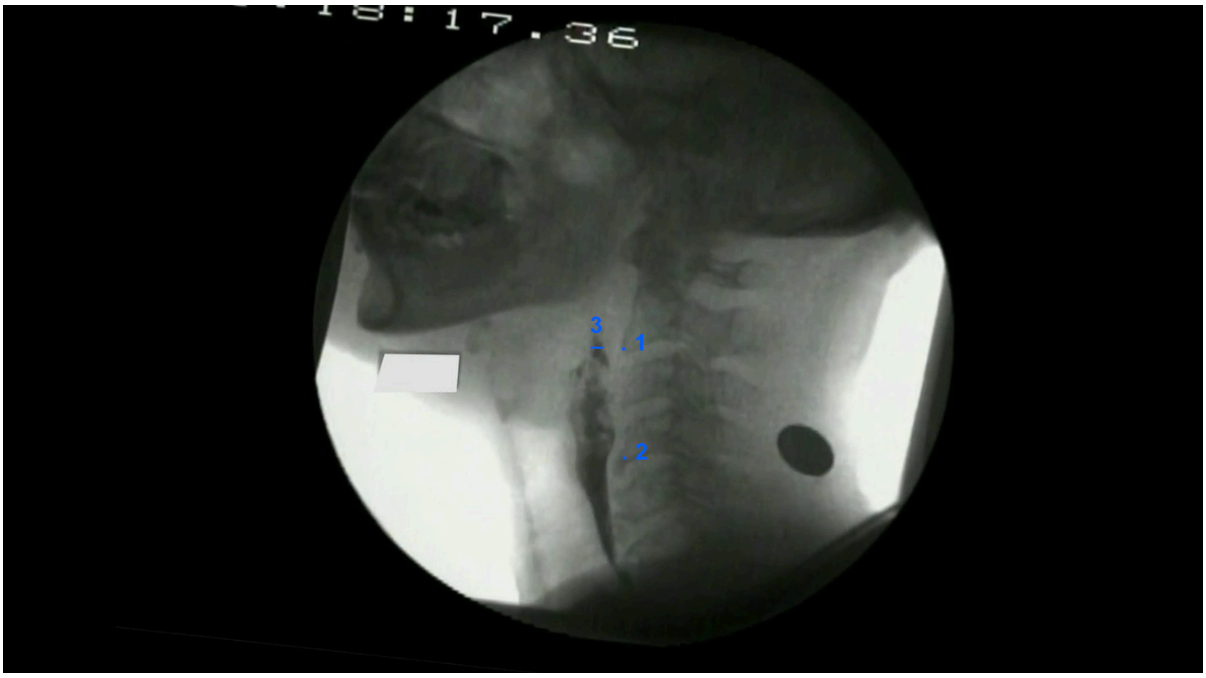
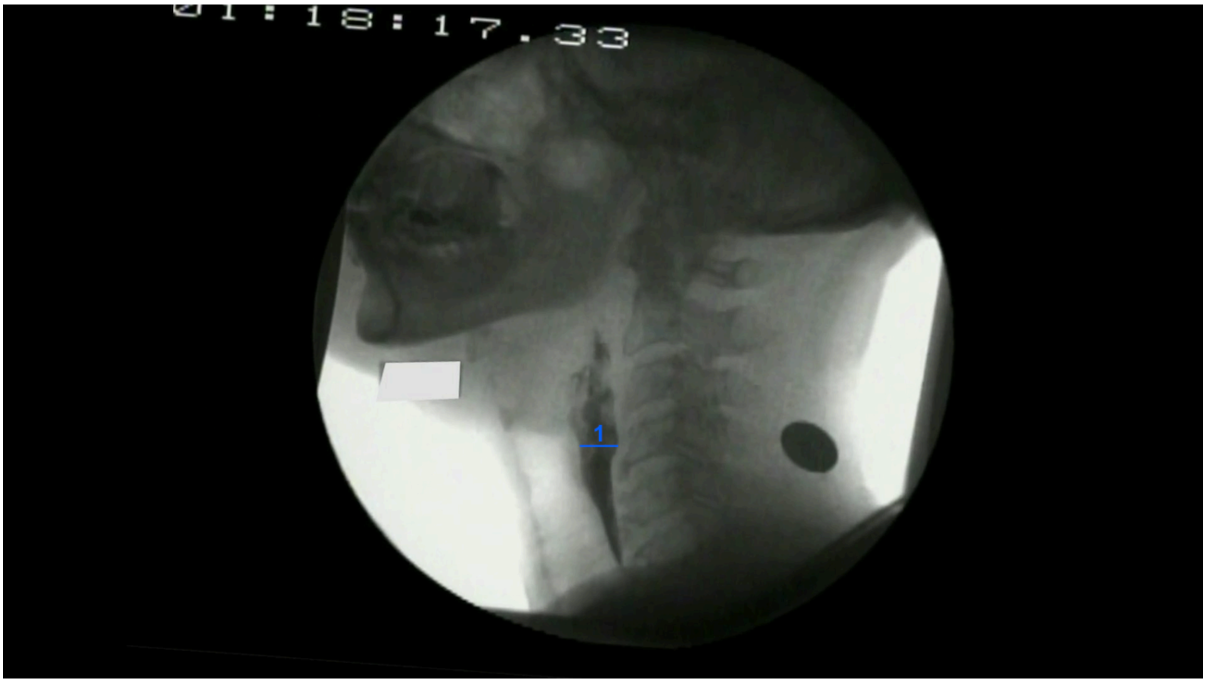


Figure 5: Frame of maximum PES opening during swallowing from VFSS sample used for practice in the study. 1. Maximum PES opening during swallowing.



Reliability Outcomes on Practice Sets

The practice MBSImP® ratings were carried out on the five selected components of MBSImP®, i.e., Component 6- initiation of pharyngeal swallow, Component 8- laryngeal elevation, Component 9- anterior hyoid excursion, Component 14- pharyngeal esophageal segment opening and Component 15-tongue base retraction. Practice ImageJ measurements were made on the proposed corresponding objective measures of onset of hyoid movement relative to onset of oral transit, maximum vertical larynx displacement at first closure of laryngeal vestibule, maximum anterior hyoid displacement, extent of anterior arytenoid movement at first closure of laryngeal vestibule, width and extent of tongue base retraction to posterior pharyngeal wall, and width of maximum cricopharyngeal opening.

On the practice sets, adequate inter-rater reliability of 80% agreement on MBSImP® ratings between the thesis candidate and the research experience student (MM) was achieved for one of the 5 components initially proposed for the study: Component 9- Anterior Hyoid Excursion. The thesis candidate and research experience students (HC & LE) achieved adequate inter-rater reliability of at least $r = .80$ on two objective displacement measures of ImageJ: maximum vertical larynx displacement at first closure of laryngeal vestibule and maximum anterior hyoid displacement. With additional practice, inter-rater reliability did not increase beyond these levels. As a result, the study proceeded with Component 9- Anterior Hyoid Excursion of MBSImP® and anterior hyoid excursion in normalized scalar units as the corresponding objective measure. Because no temporal measures of swallow were associated with Component 9, the Swallowtail software was not used further in this study.

Final Study Procedures

Final Measurements. The final study measures included MBSImP® rating of Component 9 – Anterior Hyoid Excursion and Extent of anterior hyoid excursion in normalized scalar units.

Figure 6: Summary of methodology of the study

Selection of study procedures

- 5 oro-pharyngeal components chosen from 17 MBSImP® components for the study: Component 6, Component 8, Component 9, Component 14 and Component 15.
- Corresponding objective measures were chosen after reviewing the literature.

Training in study procedures

- Thesis candidate and a graduate student (MM) took online MBSImP® training and acquired certification.
- Thesis candidate and MM trained further on the selected 5 MBSImP® components on practice VFSS sets.
- Thesis candidate and graduate student researchers (HC & LE) trained on practice VFSS sets for objective measurements.

Reliability outcomes on practice sets

- Adequate inter-rater reliability between thesis candidate and graduate student researcher (MM) achieved only on one MBSImP® component: 9- Anterior hyoid excursion.
- Adequate inter-rater reliability between thesis candidate and graduate student researchers (HC & LE) achieved on two objective measurements: Laryngeal elevation at first laryngeal closure and maximum anterior hyoid excursion.

Final Study Procedures

- MBSImP® rating of Component 9 – Anterior Hyoid Excursion and extent of maximum anterior hyoid excursion in normalized scalar units.

Videofluoroscopic Swallowing Study samples for final analysis. Two-hundred VFSS samples were selected for final analysis. Samples were from consecutive subjects referred for VFSS and met the following criteria: 1) 5 ml thin liquid bolus; 2) hyoid bone visible throughout entire swallow; 3) cervical vertebrae C2 through C4 visible throughout entire swallow. Samples were not segregated by gender or size as they were analyzed using an anatomical scalar which neutralizes the sex-based size differences in the structures (Molfenter & Steele, 2014). All the sample images used in the study for objective data collection were scaled using the distance from the anterior inferior corner of C2 to the anterior inferior corner of C4, assigning a value of 35 scalar units to the length.

To eliminate potential bias of the thesis candidate during ratings and measurements, the faculty mentor randomly assigned different identifying numbers to individual swallows for each measurement technique. For instance, ImageJ swallow i001 was named m034 for the MBSImP® rating task. After completion of all ratings and measurements, the mentor linked the ImageJ data with the corresponding MBSImP® rating using the swallow name identifying key.

Reliability of MBSImP® measurements. Target levels for inter-rater and intra-rater reliability for MBSImP® measurements was revised to 80% after the training period. Percentage agreement was chosen as the reliability measure for MBSImP® measurements and was performed for 20% of the VFSS samples. The faculty mentor used a random number generator to select VFSS samples for reliability assessment. The thesis candidate and research experience graduate student (MM) trained in MBSImP® analyzed 40 VFSS samples randomly selected as a measure of inter-rater reliability. In addition, the thesis candidate re-analyzed a different set of 40 randomly selected VFSS samples as a measure of intra-rater reliability for MBSImP®.

Reliability of objective measurements. Target levels for inter-rater and intra-rater reliability for objective measurements made with ImageJ was revised to $r \geq .80$ after the training period. The faculty mentor used a random number generator to select 20% of the VFSS samples, i.e., 40 VFSS samples for reliability assessment between the thesis candidate and the graduate students (HC & LE) who analyzed 20 samples each. For inter-rater reliability, Interclass correlation (ICC) and a Bland-Altman plot were used to determine inter-rater reliability on 40 randomly selected VFSS samples that were measured by the thesis candidate and research experience graduate students trained in ImageJ. To determine the intra-rater reliability of objective measurements, regression and R^2 were calculated on a second set of 40 randomly selected VFSS samples re-measured by the thesis candidate.

Statistical Analysis

To improve the confidence in using MBSImP® as a clinical measurement tool of oro-pharyngeal dysphagia from VFSS, the intervals in the components need to be validated. The aim of this study was to determine whether quantifiable data could be associated with the different rating levels of the components of interest in MBSImP®. This could be achieved by finding significant differences among the groups of objective data (biomechanical measures of swallowing) representing the different ordinal rating levels of the components of interest in MBSImP®. Toward that purpose, an Analysis of Variance (ANOVA) was planned. For the purpose of statistical analysis, the ordinal scale ratings of components of swallowing of MBSImP® was the independent variable and the objective data were the dependent variables.

The multiple groups of objective data representing different ordinal rating levels of MBSImP® Component 9- Anterior Hyoid Excursion obtained in the study were analyzed for statistically significant differences in their mean values. For example, to validate the intervals in three levels of rating (0, 1, 2) of Component 9 of MBSImP®, Anterior Hyoid Excursion, the objective data of maximum anterior hyoid displacement representing the three levels was taken as three groups and studied for variance in their mean values. A one way ANOVA was planned for this task. If the ANOVA showed presence of significant difference in mean values, the subsequent levels of ordinal ratings would be individually studied for variance. For example, if ANOVA showed significant difference in the three groups of data representing three levels of Component 9, objective data would be subjected to multiple comparisons to study the difference among the different levels of MBSImP® ratings. The data would be visually represented on boxplots.

Results

Originally, the aim of the study was to determine if quantifiable data could be associated with different levels of ratings of 5 MBSImP® components. However, on the practice sets, adequate inter-rater reliability of MBSImP® ratings was achieved for one of the 5 components initially proposed for the study: Component 9- Anterior Hyoid Excursion. Thus, the study was focused on determining the relationship between anterior hyoid movement as rated with MBSImP® and as measured objectively with ImageJ.

Reliability of Final Data

Inter- and intra-rater reliability of the final data demonstrated high levels of agreement.

Reliability of MBSImP® ratings. Simple percentage agreement was used as a measure of inter-rater and intra-rater reliability of MBSImP® ratings. Inter-rater percentage agreement between the thesis candidate and research experience student on MBSImP® ratings of Component 9 was 80%. Intra-rater percentage agreement of MBSImP® ratings performed by the thesis candidate was 100%.

Reliability of objective measurements. Inter-rater reliability of 40 VFSS samples measured using ImageJ between the thesis candidate and research experience students was assessed with Inter-Class Correlation (ICC). Table 3 shows a strong correlation coefficient of

0.924 which indicates high inter-rater reliability of objective data obtained using ImageJ.

Table 3: Inter-class correlation for inter-rater reliability of objective measurements.

	Inter-class Correlation	95% Confidence Interval		F test with True Value 0		
		Lower band	Upper band	Value	df1	df2
Single measures	.858	.754	.921	12.965	42	42
Average measures	.924	.860	.959	12.965	42	42

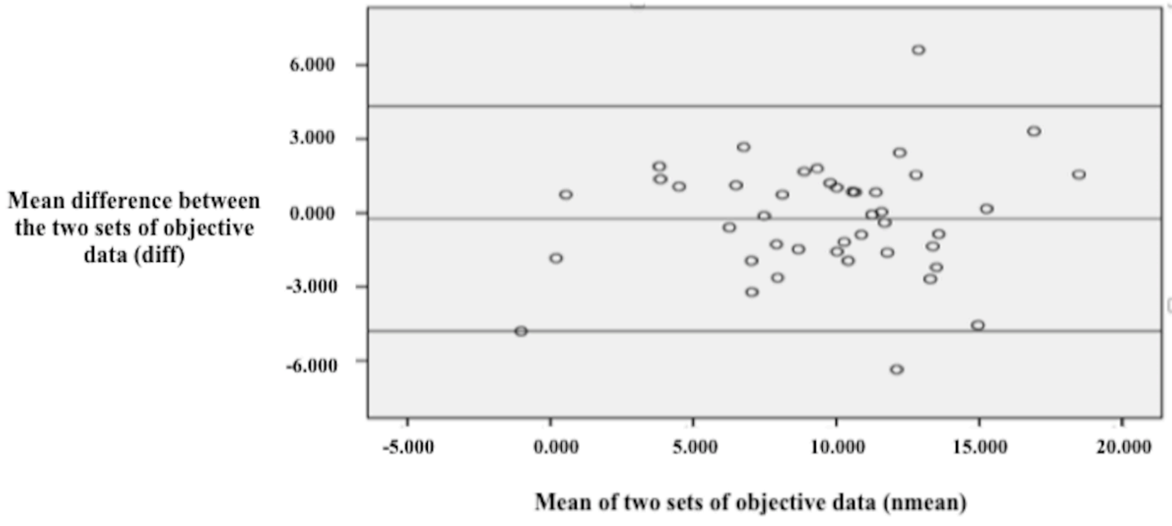
The mean difference between the two sets of measures was also studied to further understand the inter-rater reliability. As table 4 shows, the one sample t-test did not reveal a statistically significant mean difference between the two sets (-0.235), which indicates agreement between the two sets of objective data measured for the study by the thesis candidate and graduate students (HC & LE).

Table 4: One-Sample t-test

	Test Value= 0					
	t	Df	Sig. (2-tailed)	Mean difference	95% Confidence Interval of the Difference	
					Lower	Upper
diff	-.661	42	.512	-.235	-.953	.482

Finally, a Bland-Altman scatterplot was also used to investigate systematic differences between the measurements and to identify possible bias and outliers. Bland-Altman scatterplot (Figure 3) showed almost all of the data points to be clustered around the mean difference (-0.235) equally scattering within the upper and lower confidence limits which ruled out bias in the data.

Figure 7: Bland-Altman scatterplot



Intra-rater reliability of objective data obtained using ImageJ was calculated by regression analysis and calculating the slope. The two sets of objective data of 40 VFSS samples measured by the thesis candidate at two different points of time were subjected to regression analysis. The R^2 was found to be 0.966 which indicated good agreement (Table 5).

Table 5: Regression analysis and slope for intra-rater reliability of objective measurements.

					Change Statistics		
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1
1	.983[a]	.966	.965	.997	.966	1066.078	1

MBSImP® Ratings and Objective Measure Outcomes

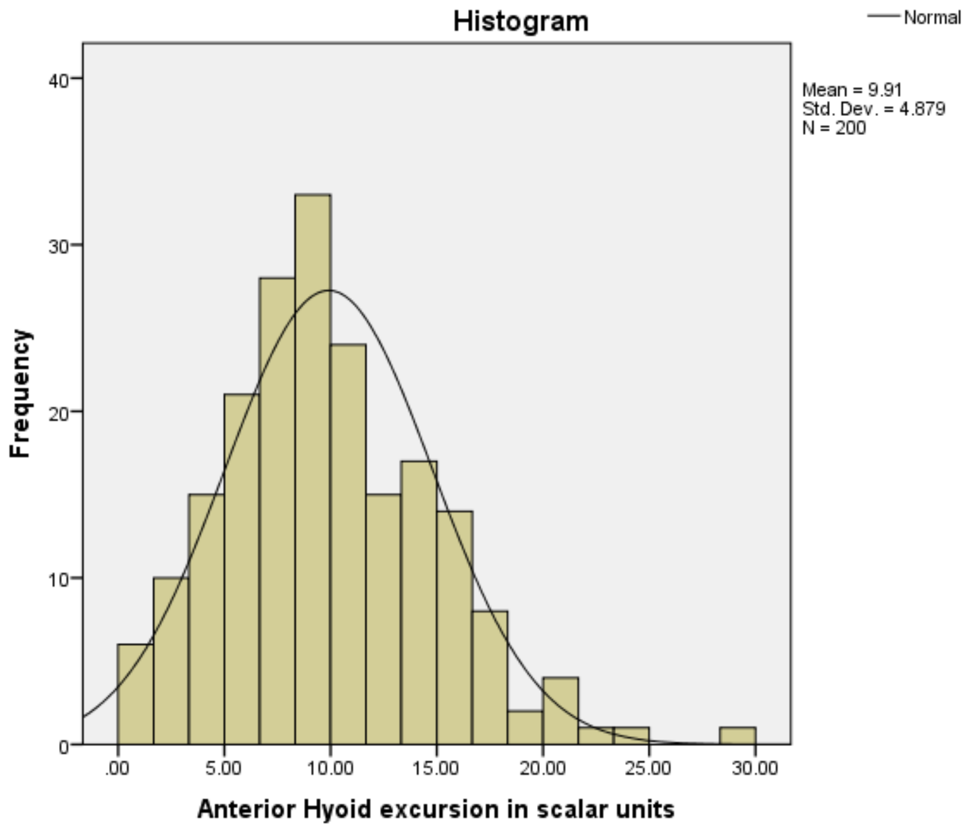
Out of 200 swallow samples analyzed for the study, 50 samples (25% of samples) were rated as 0 (complete anterior movement), 146 samples (73% of samples) were rated as 1 (partial anterior movement) and 4 samples (2% of samples) were rated as 2 (no anterior movement) on Component 9- Anterior Hyoid Excursion of MBSImP®.

Descriptive statistics of the objective data (Table 6) revealed an overall mean of 9.90 scalar units (standard deviation of 4.87 scalar units) with an overall range of 29.26 (0.18 to 29.44 scalar units). The histogram of objective data, i.e., maximum anterior hyoid excursion in scalar units obtained from ImageJ for the 200 consecutively referred subjects, revealed approximate normal distribution (Figure 1). Descriptive statistics of the objective data categorized by MBSImP® rating level (Table 7) revealed the maximum anterior hyoid excursion of samples rated 0 ranged between 1.38 and 29.44 scalar units with mean of 13.44 scalar units (standard deviation of 5.36); the maximum anterior hyoid excursion of samples rated 1 ranged between 0.82 and 20.08 scalar units with mean of 8.89 scalar units (standard deviation of 4.00); and the maximum anterior hyoid excursion of samples rated 3 ranged between 0.18 and 6.77 scalar units with mean of 2.75 scalar units (standard deviation of 2.91).

Table 6: Overall descriptive statistics of objective data

			Statistic	Std. Error
Anterior Hyoid excursion in scalar units	Mean		9.908	.345
	95% Confidence Interval for Mean	Lower Bound	9.228	
		Upper Bound	10.588	
	5% Trimmed Mean		9.740	
	Median		9.462	
	Variance		23.803	
	Std. Deviation		4.878	
	Minimum		.18	
	Maximum		29.44	
	Range		29.26	
	Interquartile Range		6.88	
	Skewness		.594	.172
	Kurtosis		.753	.342

Figure 8: Histogram of anterior hyoid excursion in scalar unit revealing normal distribution of the data.

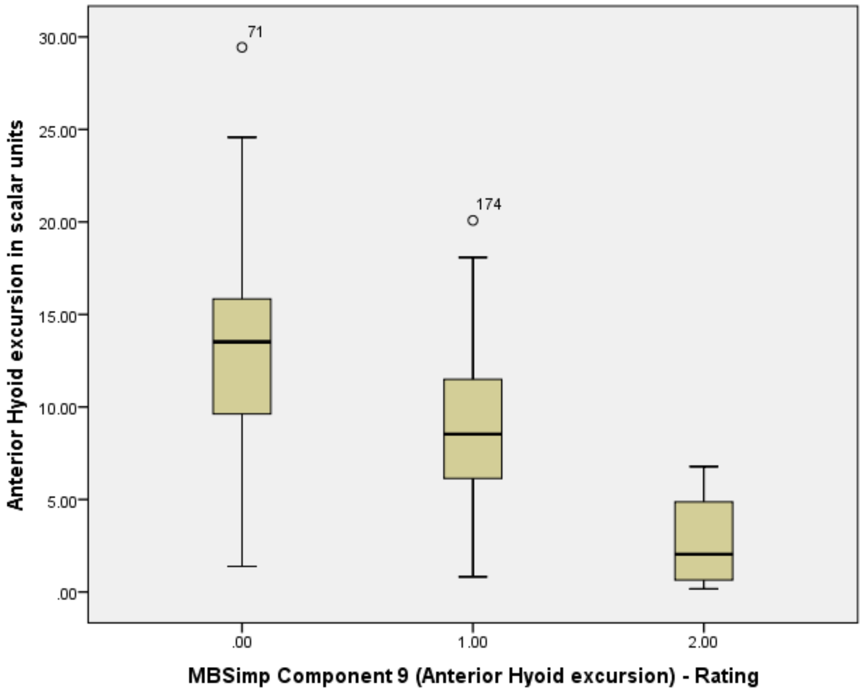


Data representation on a boxplot revealed the overall range and inter-quartile range of maximum anterior hyoid excursion among all three levels of ratings on Component 9- Anterior Hyoid Excursion of MBSImP® (Figure 2). The median of maximum anterior hyoid excursion of samples rated 0 was 13.51; median of maximum anterior hyoid excursion of samples rated 1 was 8.53; median of maximum anterior hyoid excursion of samples rated 2 was 2.04.

Table 7: Descriptive statistics of objective data categorized by MBSImP® rating level

MBSImP® Component 9 rating	N	Mean	Std. Deviation	Median	Inter-quartile range	Minimum	Maximum
0	50	13.443	5.360	13.519	6.48	1.38	29.44
1	146	8.893	4.003	8.535	5.38	.82	20.08
2	4	2.758	2.916	2.042	5.41	.18	6.77
Total	200	9.908	4.878	9.462	-	.18	29.44

Figure 9: Boxplot representation of objective data categorized by MBSImP® rating level



Statistical analysis of the data with a one way ANOVA (Table 8) revealed a statistically significant difference ($p<0.001$) in the mean of anterior hyoid excursion in scalar units among the MBSImP® ratings levels with R^2 value of 0.20. Multiple paired comparisons (Table 9) performed using the Bonferroni adjustment in SPSS revealed significant differences among all ratings levels, i.e., between 0 and 1; between 0 and 2; between 1 and 2. The multiple paired comparisons of maximum anterior hyoid excursion obtained in scalar units from objective measurements categorized by the levels of MBSImP® ratings (0, 1 and 2) of Component 9-Anterior Hyoid Excursion revealed significant mean difference of 4.54 scalar units in the maximum hyoid excursion between samples rated 0 and 1; a mean difference of 6.12 scalar units in the maximum hyoid excursion between samples rated 1 and 2 and a mean difference of 10.68 scalar units in the maximum hyoid excursion between samples rated 0 and 2.

Table 8: One way - ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig	Partial Eta Squared
MBSImP®	979.719	2	489.860	25.685	.000	.207

Table 9: Multiple comparison of objective data categorized by MBSImP® rating level

MBSImP® Component 9 Rating	MBSImP® Component 9 Rating	Mean Difference	Std. Error	Sig.
0	1	4.549*	.715	.000
1	2	6.135*	2.213	.018
0	2	10.685*	2.269	.000

*The mean difference is significant at the 0.05 level.

Discussion

Interpretation of the Results. With the first research question, the study aimed to find how the different components of MBSImP® compared with objective measures of swallowing obtainable using Swallowtail and ImageJ. Based on the literature review, the nature of ratings of the 17 components and to keep the scope of the study appropriate for a master's thesis, the focus of the study was confined to 5 components of MBSImP® that had logical relationships with published temporal and biomechanical measures of the oropharyngeal swallow. For example, the nature of rating Component 4 of MBSImP®- bolus transport as defined in the guidelines ('brisk', 'delayed', 'slow', 'repetitive' and 'minimal') did not have logical relationship with published temporal and biomechanical measures and thus, could not be objectively measured. As a result, focus was laid on 5 MBSImP® components, i.e., Component

6- initiation of pharyngeal swallow, Component 8- laryngeal elevation, Component 9- anterior hyoid excursion, Component 14- pharyngeal esophageal segment opening and Component 15- tongue base retraction, all components that could be objectively measured by temporal and biomechanical aspects. Though this limited the scope of the study, one could remark that the ratings of certain components like Component 4- bolus transport are neither completely temporal, displacement nor efficient in nature to be able to consistently relate to certain types of objective measurement for future validation attempts of the tool.

The second research question of the study aimed to find if quantifiable data could be applied to different levels of ratings of MBSImP® components. Though the focus of the study was limited to one MBSImP® component and its corresponding objective measure due to inter-rater variability on other components during practice, the study was conceptualized with the intent of making an impact on clinical or future research directions based on the answer to the second research question. The possibility of associating discrete quantifiable data to different levels of MBSImP® components would validate the different levels of ratings, thereby, supporting the concept of the tool. In this study, if discrete quantifiable data could be associated with different levels of ratings of Component 9- Anterior Hyoid Excursion (complete, partial, no excursion), then the component could be quantitatively validated and also could lead to future research works on other MBSImP® components.

Descriptive statistical analysis of the overall objective data of maximum anterior hyoid excursion in normalized scalar units showed approximate normal distribution of the data on the histogram with mean of 9.90 scalar units and standard deviation of 4.88 scalar units. Thus, the data were treated with statistical tests applicable to normally distributed data during data analysis. Descriptive statistical analysis of objective data categorized by MBSImP® levels of ratings of Component 9- Anterior Hyoid Excursion revealed the possibility of associating discrete quantifiable data to different levels of rating. As expected, there was a decrease in the mean anterior hyoid excursion in normalized scalar units as the level of MBSImP® rating increased for Component 9, i.e., mean 13.44 scalar units (standard deviation of 5.36) for level 0 rating, mean 8.89 scalar units (standard deviation of 4.00) for level 1 rating and mean 2.75 scalar units (standard deviation of 2.91) for level 2 rating. There also was a similar decrease in the median of anterior hyoid excursion in normalized scalar units as the level of MBSImP® rating increased for Component 9, i.e., 13.51 scalar units for level 0 rating, 8.53 scalar units for level 1 rating and 2.04 scalar units for level 2 rating.

A one way ANOVA showed significant differences ($p<0.001$) in the mean values of anterior hyoid excursion in normalized scalar units among the MBSImP® ratings levels and multiple comparisons of the objective data categorized by MBSImP® ratings levels showed significant differences in mean values among all three levels of rating of Component 9. However, the ANOVA revealed a low R^2 value of 0.20 which means only 20% of the variation in the objective data of anterior hyoid excursion in normalized scalar units could be explained by different levels of rating on the component of interest of MBSImP® tool. This was because of the high variation in objective data in level 0 rating (Complete excursion) and level 1 rating (Partial excursion) which led to a huge range of objective data in the mentioned levels of MBSImP® ratings (Table 7) which can also be visualized from the boxplots (Figure 2). This high variation could be attributed to factors like wide clinical variability in normal or abnormal anterior hyoid excursion during swallowing and ambiguity due to limited rating levels of Component 9 (3 levels: 0- complete anterior hyoid excursion, 1- partial anterior hyoid excursion and 0- no anterior hyoid excursion).

Clinical Implications Clinically, normality has a wide range which means normal anterior hyoid excursion as a component of swallowing has a wide range as well. This can be observed in the objective data of level 0 rating which ranged from 1.38 to 29.44 scalar units. The objective data of complete anterior hyoid excursion had a high variation and overlapped in the lower limits with partial anterior hyoid excursion which ranged from 0.82 to 20.08 scalar units and no anterior hyoid excursion which ranged from 0.18 to 6.77 scalar units. Also, the upper limits of the objective data of partial and no anterior hyoid excursion had an overlap with normal anterior hyoid excursion. Hence, the variations in the lower limits and upper limits of all three levels of anterior excursion: normal, partial and no anterior hyoid excursion may not be explained by MBSImP® Component 9 which is revealed by R^2 of ANOVA (0.20). Thus, the application of the mean or median values of the objective data categorized by different MBSImP® ratings levels, though significantly different, should be done with an understanding of the possibility of these variations. This means that clinically, all three levels of anterior hyoid excursion ratings may have a wider range and overlap with each other and therefore should not be treated as completely discrete levels. The mean values of different levels of ratings could be used as a guide while doing the ratings on Component 9 of MBSImP®, however, this should be done with the understanding of the possible variations.

Relationship to Previous Research. MBSImP® was established with the purpose of addressing the lack of standardization of VFSS procedure, interpretation and reporting (Martin-Harris et al., 2008). The authors recommend online training and certification before using the tool for clinical or research purposes for ensuring reliability of ratings. Thus, before the actual data collection for the study, the student researchers completed the online training (between December 2017 and March 2018) and achieved the required 80% reliability in the reliability zones after multiple attempts (> 10 attempts) for certification. To improve the reliability of the data to be used in the study, the student researchers were additionally required to work on practice sets of VFSS samples and achieve 90% inter-rater reliability which was later revised to 80% during the course of the study.

Although the authors have standardized the MBSImP® tool on a large population and found the tool to have high levels of reliability and validity (Martin-Harris et al., 2008), student researchers even after undergoing online MBSImP® training and acquiring certification, achieved the required inter-rater reliability only on Component 9- Anterior Hyoid Excursion on practice sets. The variability in the inter-rater ratings on other targeted components could be attributed to lack of common understanding of MBSImP®components, its ratings and availability of limited VFSS samples in the learning, training and reliability zones of the online MBSImP® training program. Also, the student researchers expressed difficulty in conceptualizing the guidelines for ratings of different components of MBSImP®. For example, the rating for Component 15- tongue base retraction is done by observation of 'no', 'trace', 'narrow' or 'wide' air column between tongue base and posterior pharyngeal wall at the point of maximum tongue base retraction during swallowing which included the likelihood of subjectivity. However, the component and rating could not be adequately conceptualized due to indistinct defining of site of observation and the criteria for different levels of ratings which led to high variability in the ratings between the thesis candidate and graduate student researcher (MM) on practice sets.

Similarly, there was high variability in the MBSImP®ratings of Component 6- initiation of pharyngeal swallow, Component 8- laryngeal elevation and Component 14- pharyngeal esophageal segment opening on the practice sets. Adequate inter-rater reliability was achieved only on Component 9- Anterior Hyoid Excursion on practice sets. Though during the training for objective measurements on the practice sets, adequate inter-rater reliability between thesis candidate student researchers (HC & LE) was achieved on two objective measures using ImageJ: maximum vertical larynx displacement at first closure of laryngeal vestibule and maximum anterior hyoid displacement, the focus of the study had to be limited to Component 9- Anterior Hyoid Excursion of MBSImP® and anterior hyoid excursion as the corresponding objective measure.

Limitations of the Study and Implications for Future Research. In the study, a large number of samples were rated as 1 (73%) possibly due to limited number of rating levels of MBSImP® Component 9. There was only one level between completely normal and abnormal anterior hyoid excursion of swallowing and thus, a high number of VFSS samples were rated as 1. This led to high variability of objective data in the level 1 rating of MBSImP® Component 9. This would lead to high variability in the clinical usage of this component of the MBSImP® tool. Having four clearly defined levels of ratings with 2 levels of ratings between completely normal and abnormal anterior hyoid excursion of swallowing might reduce this variability, thereby adding ease and accuracy of understanding anterior hyoid excursion of swallowing from the clinician's rating on MBSImP® Component 9.

As already discussed, not all the components and ratings could be adequately conceptualized due to indistinct defining of site of observation and the criteria for different levels of ratings, which led to high variability in the ratings by the thesis candidate and research experience student (MM) on practice sets. Thus, the terms used to categorize different levels of ratings of various MBSImP® components could be more concretely defined to reduce variability in the ratings. For example, subjective terms like 'no', 'trace', 'narrow' and 'wide' could be more clearly defined to improve the objectivity of ratings.

Although MBSImP® guidelines for component 9- anterior hyoid excursion emphasize basing its rating on only the anterior movement of the hyoid bone, it was difficult to completely ignore co-occurring biomechanical events such as movement in the vertical plane or on the diagonal during swallowing. These co-occurring biomechanical events acted as distractors while rating the component 9 of MBSImP® and could have induced bias in ratings, thereby increasing the variability in the data. Although the thesis candidate or the graduate student researcher (MM) did not attempt to specifically identify all the potential distractors while rating component 9 of MBSImP®, they did realize the possibility during the course of the study. An improved online training zone for MBSImP® could target this factor in greater depth to reduce this bias while rating this component.

The study explored only one component out of the originally selected 5 MBSImP® components due to low inter-rater reliability on practice sets. The study proceeded with Component 9 due to time constraints and thus, future studies can focus on the other 4 MBSImP® components. If the tool is modified in the future in terms of nature of rating of the components to have logical relationships with available temporal, biomechanical and efficiency measures in the literature, other components could be also studied for validation of different levels of ratings by association with quantifiable data. Though this study could not satisfactorily prove the concept of the tool due to high variability, the objective data of anterior hyoid excursion in normalized scalar units categorized by rating levels of MBSImP®- anterior hyoid excursion show the potential to achieve this in the future.

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Appendix

Modified Barium Swallow Impairment Profile (MBSImP®)

The MODIFIED BARIUM SWALLOW IMPAIRMENT PROFILE: MBSImP ™ © Components, Scores, and Score Definitions

ORAL Impairment

Component 1—Lip Closure
0 = No labial escape
1 = Interlabial escape; no progression to anterior lip
2 = Escape from interlabial space or lateral juncture; no extension beyond vermilion border
3 = Escape progressing to mid-chin
4 = Escape beyond mid-chin

Component 2—Tongue Control During Bolus Hold
0 = Cohesive bolus between tongue to palatal seal
1 = Escape to lateral buccal cavity/floor of mouth (FOM)
2 = Posterior escape of less than half of bolus
3 = Posterior escape of greater than half of bolus

Component 3—Bolus Preparation/Mastication
0 = Timely and efficient chewing and mashing
1 = Slow prolonged chewing/mashing with complete re-collection
2 = Disorganized chewing/mashing with solid pieces of bolus unchewed
3 = Minimal chewing/mashing with majority of bolus unchewed

Component 4—Bolus Transport/Lingual Motion
0 = Brisk tongue motion
1 = Delayed initiation of tongue motion
2 = Slowed tongue motion
3 = Repetitive/disorganized tongue motion
4 = Minimal to no tongue motion

Component 5 – Oral Residue
0 = Complete oral clearance
1 = Trace residue lining oral structures
2 = Residue collection on oral structures
3 = Majority of bolus remaining
4 = Minimal to no clearance

Location
A = Floor of mouth (FOM)
B = Palate
C = Tongue
D = Lateral sulci

Component 6—Initiation of Pharyngeal Swallow
0 = Bolus head at posterior angle of ramus (first hyoid excursion)
1 = Bolus head in valleculae
2 = Bolus head at posterior laryngeal surface of epiglottis
3 = Bolus head in pyriforms
4 = No visible initiation at any location

PHARYNGEAL Impairment

Component 7—Soft Palate Elevation
0 = No bolus between soft palate (SP)/pharyngeal wall (PW)
1 = Trace column of contrast or air between SP and PW
2 = Escape to nasopharynx
3 = Escape to nasal cavity
4 = Escape to nostril with/without emission

Component 8—Laryngeal Elevation
0 = Complete superior movement of thyroid cartilage with complete approximation of arytenoids to epiglottic petiole
1 = Partial superior movement of thyroid cartilage/partial approximation of arytenoids to epiglottic petiole
2 = Minimal superior movement of thyroid cartilage with minimal approximation of arytenoids to epiglottic petiole
3 = No superior movement of thyroid cartilage

Component 9—Anterior Hyoid Excursion
0 = Complete anterior movement
1 = Partial anterior movement
2 = No anterior movement

Component 10–Epiglottic Movement
0 = Complete inversion
1 = Partial inversion
2 = No inversion

Component 11—Laryngeal Vestibular Closure – Height of Swallow
0 = Complete; no air/contrast in laryngeal vestibule
1 = Incomplete; narrow column air/contrast in laryngeal vestibule
2 = None; wide column air/contrast in laryngeal vestibule

Component 12—Pharyngeal Stripping Wave
0 = Present - complete
1 = Present - diminished
2 = Absent

Component 13—Pharyngeal Contraction (*A/P VIEW ONLY*)
0 = Complete
1 = Incomplete (Pseudodiverticulae)
2 = Unilateral Bulging
3 = Bilateral Bulging

Component 14—Pharyngoesophageal Segment Opening
0 = Complete distension and complete duration; no obstruction of flow
1 = Partial distension/partial duration; partial obstruction of flow
2 = Minimal distension/minimal duration; marked obstruction of flow
3 = No distension with total obstruction of flow

Component 15—Tongue Base (TB) Retraction
0 = No contrast between TB and posterior pharyngeal wall (PW)
1 = Trace column of contrast or air between TB and PW
2 = Narrow column of contrast or air between TB and PW
3 = Wide column of contrast or air between TB and PW
4 = No visible posterior motion of TB

Component 16—Pharyngeal Residue
0 = Complete pharyngeal clearance
1 = Trace residue within or on pharyngeal structures
2 = Collection of residue within or on pharyngeal structures
3 = Majority of contrast within or on pharyngeal structures
4 = Minimal to no pharyngeal clearance

Location
A = Tongue Base
B = Valleculae
C = Pharyngeal wall
D = Aryepiglottic folds
E = Pyriform sinuses
F = Diffuse (>3 areas)

ESOPHAGEAL Impairment

Component 17—Esophageal Clearance Upright Position
0 = Complete clearance; esophageal coating
1 = Esophageal retention
2 = Esophageal retention with retrograde flow below pharyngo-esophageal segment (PES)
3 = Esophageal retention with retrograde flow through PES
4 = Minimal to no esophageal clearance