THE EFFECTS OF A DEVICE-MEDIATED LINGUAL STRENGTHENING PROTOCOL ON RADIATION AND CHEMORADIATION INDUCED DYSPHAGIA

by

Natalie Bradshaw

BFA Musical Theater, University of Cincinnati, 2007

Submitted to the Graduate Faculty of

School of Health and Rehabilitation Sciences in partial fulfillment

of the requirements for the degree of

Master of Science, Communication Science and Disorders

University of Pittsburgh

2017

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

This thesis was presented

by

Natalie Bradshaw

It was defended on

November 11, 2016

and approved by

Paula Leslie, PhD, Professor, Department of Communication Science and Disorders

Katherine Verdolini-Abbott PhD, Professor, Departments of Communication Science and Disorders and Otolaryngology

Erin Lundblom PhD, Assistant Professor, Department of Communication Science and Disorders

Thesis Director: James L. Coyle, PhD, Associate Professor, Departments of Communication Science and Disorders and Otolaryngology

THE EFFECTS OF A DEVICE-MEDIATED LINGUAL STRENGTHENING PROTOCOL ON RADIATION AND CHEMORADIATION INDUCED DYSPHAGIA

Natalie Bradshaw, MS

University of Pittsburgh, 2017

Introduction: Dysphagia, or disordered swallowing, is frequently found in patients with head and neck cancer due to side-effects of non-surgical interventions including radiation and chemoradiation therapies. Device-mediated lingual strengthening exercises have a theoretical basis for effectively mitigating dysphagia in this population, but these exercises have not been shown to be beneficial in the research literature to date. The primary goal of this study was to describe the effects of a device-mediated lingual strengthening protocol, added to standard behavioral therapy, on overall swallowing function as reflected by videofluoroscopic analysis. The secondary goal was to describe performance related observations regarding participant characteristics.

Methods: This was a secondary examination of the data from six participants in a larger prospective experimental study. Three participants, assigned to the control group, completed "standard dysphagia therapy," and three participants, assigned to the experimental group, completed a device-mediated lingual strengthening protocol in addition to "standard dysphagia therapy." Videofluoroscopic data was collected for all six participants "pre" and "post" treatment. Measurements of videofluoroscopic data were taken for seven durational swallowing kinematic measures, penetration-aspiration scale scores, and pharyngeal retention scale scores. These measurements were taken to assess airway protection, pharyngeal reside, and overall

biomechanical efficiency. Only penetration-aspiration scale scores and pharyngeal retention scores were analyzed, due to feasibility. Analysis consisted of mean differences and a normalization to baseline data transformation.

Results: Findings revealed a lack of consistent improvements in all participants across all dependent variables. However, two observations were made regarding the medical characteristics of the participants. Specifically, the greatest performance was seen by participants who had less than one year between finishing chemoradiation therapy and commencing dysphagia treatment and who presented with primary lesions in the tonsillar region.

Discussion: No consistent improvements were found to support the addition of device-mediated lingual strengthening exercise to "standard dysphagia therapy," possibly due to variations in the small sample size and flaws in methodology. However, observations indicate that this form of intervention may be useful for patients seeking dysphagia treatment early with primary lesions in the tonsillar region.

TABLE OF CONTENTS

PREFACE ..... **XII**

1.0 INTRODUCTION **1**

1.1 SWALLOWING **1**

1.1.1 Oral phase **2**

1.1.2 Pharyngeal phase **4**

1.1.3 Esophageal phase **6**

1.1.4 Biomechanics summary **6**

1.2 DYSPHAGIA **7**

1.3 CURRENT PRACTICES IN DYSPHAGIA MANAGEMENT **8**

1.3.1 Dysphagia screening **8**

1.3.2 Dysphagia assessment **9**

1.3.3 Dysphagia treatment **13**

1.3.4 Exercise overview **14**

1.3.5 Muscular strength training in dysphagia therapy **15**

1.3.6 Efficacy studies **17**

1.4 HEAD AND NECK CANCER **18**

1.4.1 Personal demographic information **19**

1.4.2 Medical history factors **20**

1.4.3 Dysphagia in patients with head and neck cancer **26**

1.4.4 Current treatments for radiation/ chemoradiation-induced dysphagia **27**

1.5 RESEARCH QUESTIONS **31**

2.0 METHODS 34

2.1 ETHICS 34

2.2 STUDY DESIGN AND DESCRIPTION 34

2.3 PARTICIPANTS, GROUP ASSIGNMENTS 35

2.4 TREATMENT PROTOCOLS 36

2.4.1 "Standard dysphagia therapy" treatment protocol 36

2.4.2 Device-mediated lingual strengthening exercise protocol 37

2.5 VIDEOFLUOROSCOPIC DATA COLLECTION 38

2.6 VIDEOFLUOROSCOPIC DATA MANAGEMENT 40

2.7 MEASUREMENT 40

2.8 MEASUREMENT FIDELITY 42

2.8.1 Blinding 43

2.8.2 Training 43

2.8.3 Reliability testing (experimental data set) 45

2.9 ANALYSIS 46

3.0 RESULTS 47

3.1.1 Participant A (experimental group) 48

3.1.2 Participant C (experimental group) 49

3.1.3 Participant E (experimental group) 51

3.1.4 Participant B (control group) 52

3.1.5 Participant D (control group) 54

3.1.6 Participant F (control group) 55

4.0 DISCUSSION 58

4.1 RESEARCH QUESTION 1 58

4.2 RESEARCH QUESTION 2 62

4.2.1 Timing 63

4.2.2 Location 63

4.2.3 Staging 64

4.2.4 Age and gender 65

4.2.5 Summary 66

4.3 STUDY STRENGTHS AND LIMITATIONS 67

5.0 CONCLUSION 71

5.1 SUMMARY 71

5.2 SIGNIFICANCE 72

APPENDIX A 74

BIBLIOGRAPHY 79

LIST OF TABLES

Table 1: TNM staging used for patients with head and neck cancer 21

Table 2: Exercises prescribed in “Standard dysphagia therapy” 37

Table 3: Exercise treatment timeline 38

Table 4: Description of swallow conditions 39

Table 5: Penetration-aspiration scores 41

Table 6: Pharyngeal retention scores 42

Table 7: Initial inter-rater reliability results (training data) 44

Table 8: Inter-rater reliability results following consensus (training data) 44

Table 9: Intra-rater reliability testing results (training) 45

Table 10: Inter-rater reliability testing results (experimental data set) 46

Table 11: Intra-rater reliability testing results (experimental data set) 46

Table 12: Participant characteristics 47

Table 13: Penetration-aspiration scores, Participant A 48

Table 14: Pharyngeal retention scores (valleculae), Participant A 49

Table 15: Pharyngeal retention scores (pyriform sinus), Participant A 49

Table 16: Penetration-aspiration scores, Participant C 50

Table 17: Pharyngeal retention scores (valleculae), Participant C 50

Table 18: Pharyngeal retention scores (pyriform sinus), Participant C 50

Table 19: Penetration-aspiration scores, Participant E 51

Table 20: Pharyngeal retention scores (valleculae), Participant E 52

Table 21: Pharyngeal retention scores (pyriform sinus), Participant E 52

Table 22: Penetration-aspiration scores, Participant B 53

Table 23: Pharyngeal retention scores (valleculae), Participant B 53

Table 24: Pharyngeal retention scores (pyriform sinus), Participant B 53

Table 25: Penetration-aspiration scores, Participant D 54

Table 26: Pharyngeal retention scores (valleculae), Participant D 55

Table 27: Pharyngeal retention scores (pyriform sinus), Participant D 55

Table 28: Penetration-aspiration scores, Participant F 56

Table 29: Pharyngeal retention scores (valleculae), Participant F 56

Table 30: Pharyngeal retention scores (pyriform sinus), Participant F 57

LIST OF FIGURES

Figure 1. Events in the oral preparatory and oral transit phases (liquid bolus) 4

Figure 2. Events in the pharyngeal phase 6

Figure 3: Visual explanation of pharyngeal retention scale alterations 42

PREFACE

Many thanks to the giants who've lent me their shoulders. Without you, this study would not have been possible. First and foremost, my deepest thanks to my advisor and mentor Dr. James Coyle. Thank you for your sagacious guidance, generosity, and patience throughout this process. Additionally, thank you for instilling in me a thirst for clinical knowledge and a passion for helping people with dysphagia.

I would also like to thank the principal investigators of the larger ongoing study, specifically Dr. Liddy Smith, Ms. Tami Wasserman-Winkco, Dr. Jonas Johnson, and Dr. James Coyle, for their generosity and confidence. Thank you for trusting me with your primary data.

In addition, many thanks to fantastic SLP team at UPMC Presbyterian. Thanks to Tami Wasserman-Wincko for her patience, encouragement, and advice over the past eleven months. Thanks to Jessica Jordan for her patience and consistent updates, and thanks to Keely Anthony for her guidance and for always knowing where to find blank CDs.

Thanks to my brilliant thesis committee, Dr. Paula Leslie, Dr. Katherine Verdolini Abbott, and Dr. Erin Lundblom. Without your expert direction and encouragement, I never would've made it this far. Last, many thanks to Sarah Pomfret and Atsuko Kurosu for their help in training, their reassurances during challenges, and their generosity in sharing lab space with me.

Why: this work is near and dear to my heart because of the many people I love who have battled this insane disease. Thank you for your support throughout this process, and for encouraging me to do what I can to contribute something to the fight.

Figures: the figures in this text were all created by myself, the author. They are meant to give readers a general sense of biomechanical events and are not anatomically accurate or drawn to scale. Therefore, readers should use caution when examining the figures contained in this text.

1.0 INTRODUCTION

Humans love to eat and drink. This love makes sense, as both nutrition and hydration are needed for survival. However, humanity's love of sustenance runs much deeper than basic biology. Consuming foods and beverages creates joy and influences appetite, it also provides comfort and even a means of personal expression. We reflect our attitudes toward health, our life experiences, and our cultural and spiritual beliefs through our food and beverage choices (Kenny, 2015). However, for people with head and neck cancer, this love may be lost, as swallowing impairments are common side effects of life-saving cancer treatments. Prepensely, this study examines the potential of a restorative lingual strengthening exercise protocol in mitigating dysphagia in patients with head and neck cancer.

1.1 SWALLOWING

At first glance, the ability to swallow appears rudimentary, but swallowing is one of the most complex physiological processes in the human body. Successful movement of material from the oral cavity to the esophagus requires over 30 oropharyngeal nerves and muscles to work together in concert, with both precise timing and movement. This need for precision is due to pressure dynamics. Proper pressure dynamics can only be obtained when oropharyngeal muscles and nerves function at exactly the right times. To obtain a better understanding of these complexities,

clinicians and researchers have developed a system to artificially separate swallowing biomechanics into three distinct phases: oral, pharyngeal, and esophageal (Coyle, 2012). Biomechanics occurring in these phases are explained below, as swallowing impairments in patients with head and neck cancer are often related to biomechanical changes.

1.1.1 Oral phase

During the oral phase of thin liquid swallows, material is accepted into the mouth where it is shaped into a manageable packet, or bolus (Matsuo & Palmer, 2008). The bolus is then propelled posteriorly into the pharynx by the tongue (Lazarus, J. A. Logemann, C. F. Huang, & A. W. Rademaker, 2003). The oral phase ends when the bolus crosses the ramus of the mandible (jaw) and enters the pharynx (Lof & Robbins, 1990). The more recent literature further divides this phase into two sections for the purpose of biomechanical analysis, the oral preparatory phase and the oral transit phase (Matsuo & Palmer, 2008).

The oral preparatory phase is the initial portion of the oral phase, consisting of mastication (rotary chewing), salivation, and oral sensation/ enjoyment, as well as bolus formation and oral containment (Coyle, 2012). Bolus formation and oral containment are interrelated as material must be successfully held within the mouth for a bolus to be formed. Successful oral holding requires barriers at both the anterior and posterior aspects of the oral cavity to prevent passive loss of material (Smith, 2012). In the anterior position, this is typically accomplished by sealing the lips. However, it may be achieved through other compensatory gestures such as a “chin up” posture, or even tongue and cheek movements (commonly seen in people who chew with their mouth open). The posterior barrier, a barrier accomplished with linguavelar valving, is formed by the tongue base being raised to meet the palatoglossus and styloglossus muscles, forming a tight

seal (Matsuo & Palmer, 2008). For the tongue to function efficiently, it must have a stable base. Lingual muscles anchor to both stable attachments (i.e. the skull base), as well as to moveable bones such as the mandible and hyoid. For moveable attachments, stabilization is accomplished through opposing muscular contraction forces including the genioglossus, hyoglossus, masseter, lateral and medial pterygoids, temporalis, and anterior external laryngeal muscles (Coyle, 2012).

The oral transit phase is the final portion of the oral phase, in which the bolus is transported from the anterior to the posterior boundaries of the oral cavity before successful propulsion into the pharynx (Ward, 2009). Transportation is accomplished through varying pressure dynamics created by lingual propulsion, linguavelar valve opening, and velopharyngeal port closure (Matsuo & Palmer, 2008). Intrabolus pressure must be both generated and maintained during this phase.

The physics principle of Boyle's Law governs this process. This law states that within a closed system, volume and pressure (potential energy) have an inverse relationship when the temperature remains constant (Krauskopf, Beiser, & Carey, 1997). Lingual movement in a closed oral cavity, as seen during oral transit, decreases the volume of the oral cavity which in turn increases the pressure (potential energy) within the oral cavity. As the linguavelar valve opens, volume increases creating a pressure gradient which propels the bolus (kinetic energy) out of the oral cavity and into the pharynx (Coyle, 2012). This propulsion is amplified by applied force through lingual muscular effort (Nicosia & Robbins, 2001; Smith, 2012). This combined process is referred to as pressure generation.

Pressure maintenance refers to the valve functioning and timing that must occur to preserve intrabolus pressure throughout the swallow (Coyle, 2012). In the oral transit phase, adequate oral containment and velopharyngeal closure keep material out of the pharyngeal and nasal cavities. Containment ensures that intrabolus pressure is maintained throughout this phase.

Figure 1 depicts some of the events which occur in the oral preparatory and oral transit phases of the swallow. Specifically, Panel 1 depicts bolus shaping, and Panel 3 depicts lingual propulsion of the bolus into the pharynx.

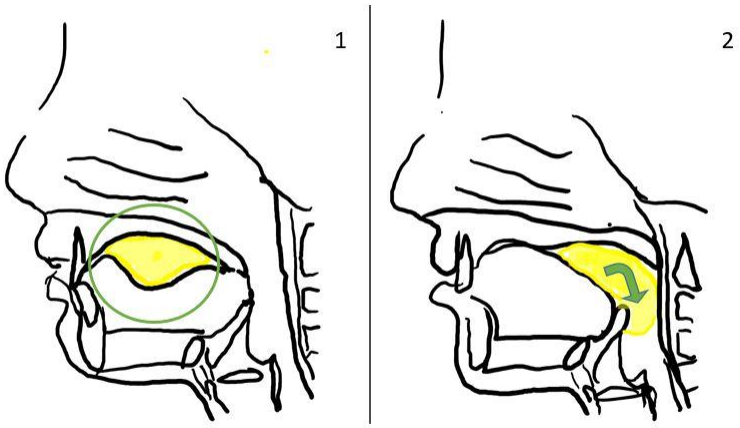

Figure 1. Events in the oral preparatory and oral transit phases (liquid bolus)

1.1.2 Pharyngeal phase

The pharyngeal phase begins with hyolaryngeal excursion, that is the vertical and anterior movement of the hyolaryngeal complex, including the hyoid bone and larynx (laryngeal vestibule, aryepiglottic folds, laryngeal ventricle, true vocal folds, and cricoid and thyroid cartilages) (Ward, 2009). This movement creates the conditions necessary for a successful swallow, primarily the transfer of the bolus into the digestive system and simultaneous airway closure and protection (Matsuo & Palmer, 2008).

For the bolus to enter the digestive system, it must be simultaneously propelled successfully through the pharynx and into the esophagus, the airway must close, and the esophagus must open. In the pharyngeal phase, *propulsion* is accomplished via posterior and inferior

movement of the tongue and tongue base along with superior to inferior compression of the tube formed by the pharyngeal constrictor muscles (Smith, 2012).

Airway protection is accomplished through hyolaryngeal excursion which displaces the larynx anteriorly and reorients the epiglottis over the laryngeal inlet, and by laryngeal shortening. The larynx remains sealed for the duration of this portion of the swallow. Intrinsic laryngeal muscles contract both shortening the laryngeal cavity and sealing the airway through adduction of the true vocal folds (Coyle, 2012). The epiglottis is also thought to play a role in airway protection, although evidence suggests that this role has been highly overstated (Jamal, Erman, & Chhetri, 2015). Specifically, a combination of intrabolus pressure and hyolaryngeal excursion force the epiglottis downward, covering the laryngeal vestibule (Ward, 2009).

Upper esophageal opening is accomplished through three mechanisms. First, a neurologic inhibitory reflex momentarily reduces the resting pressure of the cricopharyngeal portion of the inferior pharyngeal constrictor muscle, which serves as the inlet to the upper esophageal sphincter (Coyle, 2012). Second, movement during hyolaryngeal excursion displaces the cricoid cartilage both vertically and anteriorly (Smith, 2012). As the cricoid cartilage attaches to the anterior portion of the upper esophageal sphincter, the vertical and anterior movement of the hyolaryngeal complex pulls the upper esophageal sphincter open. In healthy individuals, this movement coincides with total relaxation of the upper esophageal sphincter (Coyle, 2012). Third, ongoing pressure generation, by the tongue base and pharyngeal constrictors, continues to propel the bolus into the esophagus (Matsuo & Palmer, 2008).

Figure 2 depicts biomechanical events occurring in the pharyngeal phase. Specifically, Panel 1 depicts the pharynx and larynx at rest. Panel 2 depicts hyolaryngeal excursion, epiglottic

inversion, and pharyngeal constriction. The last panel, Panel 3, depicts material passing into the upper esophageal sphincter and the start of the esophageal phase.

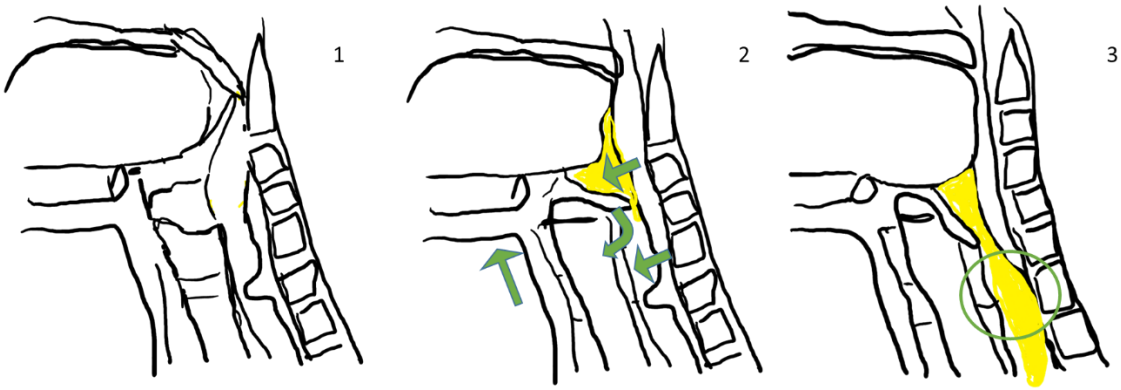

Figure 2. Events in the pharyngeal phase

1.1.3 Esophageal phase

The esophageal phase is the final stage of the swallow. During this phase, the bolus is propelled downward through the upper esophageal sphincter and into the esophagus, a 25-centimeter fibromuscular tube which passes behind the trachea and heart, and through the diaphragm (Marieb, 2011). Propulsion is accomplished through peristaltic, or wave-like muscle contractions, which force swallowed material through the esophagus and into the stomach (Matsuo & Palmer, 2008).

1.1.4 Biomechanics summary

While the oral, pharyngeal, and esophageal phases offer a well-ordered explanation of swallowing, they are not entirely accurate. In reality, phases do not occur in isolation, and biomechanics in one phase affect the next phase (Matsuo & Palmer, 2008). Phases also overlap (Coyle, 2012), requiring

the body to multi-task. As swallowing biomechanics are precise, even minor changes may disrupt a person's ability to swallow. This disruption is called dysphagia.

1.2 DYSPHAGIA

Dysphagia, i.e. disordered swallowing, is not a disease but a consequence of other processes, such as vascular trauma, neurogenic disease, and neoplasm (cancer) (Matsuo & Palmer, 2008). Iatrogenic dysphagia is a special category of dysphagia, involving an acquired pattern of disordered swallowing caused by medical interventions such as anesthesia, prolonged endotracheal intubation, operative trauma, radiation therapies, and pharmaceutical side-effects. This type of dysphagia will be discussed in further detail later in the paper, as it is the primary focus of this study, due to the prevalence of iatrogenic dysphagia in patients with head and neck cancer.

Regardless of the etiology, dysphagia impacts many areas of a patient's life, including both their personal and psychosocial health. Negative personal health outcomes may stem directly from dysphagia, including life-threatening conditions such as airway obstruction, inadequate nutrition, inadequate hydration, and difficulties ingesting medications and controlling blood glucose levels (Coyle, 2012; Matsuo & Palmer, 2008). Dysphagia may also result in negative health outcomes due to associated complications, such as aspiration. Aspiration is the penetration of material into the larynx and trachea below the level of the vocal folds (Coyle, 2012), this penetration may lead to the development of bronchopulmonary diseases. The most common bronchopulmonary disease associated with aspiration is pneumonia (Marik 2001). Dysphagia, while not an independent

predictor of pneumonia, does place individuals at an increased risk for the development of this serious, and potentially fatal, condition (Langmore et al., 1998).

1.3 CURRENT PRACTICES IN DYSPHAGIA MANAGEMENT

As dysphagia may lead to severely negative personal health outcomes, health professionals who specialize in dysphagia aim to mitigate patient harm and facilitate improvement where possible. Speech-language pathologists, or clinicians, are relevant service providers for patients with dysphagia, due to their roles in diagnosis and management. Clinician involvement may take many forms, including administering screening and assessment measures, as well as planning, implementing, and tracking patient progress during treatment.

1.3.1 Dysphagia screening

Screening protocols are an essential part of comprehensive health care, as screening measures identify patients who may be at risk for specific diseases or disorders. For a screening tool to be effective, it must be quick, accurate, and easy to administer. Consequently, screening protocols are simple by design, typically producing an easy-to-read "pass or fail" outcome. While specialists may administer screening tests, many tests may also be administered by non-specialists. In regards to screening measures specific to dysphagia, numerous options are currently available. These options range from formal protocols, such as the Yale Swallow Protocol (Suiter, Sloggy, & Leder, 2014) and the Toronto Bedside Swallowing Screening Test (TOR-BSST) (Martino et al., 2009),

to informal approaches such as patient observation. This diversity allows health care professionals to choose screening measures based on the needs of their patient.

1.3.2 Dysphagia assessment

In contrast, dysphagia assessment is more complex. These measures must be administered by specialists and provide substantially more information. Consequently, dysphagia assessments may result in a formal dysphagia diagnosis, whereas screening cannot. Dysphagia assessment also takes many different forms, and each different form provides unique information about different aspects of a patient's life. Therefore, a comprehensive assessment battery must feature different forms of assessment. Commonly used forms of dysphagia assessment include patient reports, non-instrumental evaluations, and instrumental evaluations.

Patient reports are uniquely valuable to clinicians as they provide information from the patient's perspective. Specifically, these approaches enable clinicians to ascertain knowledge regarding the patient's personal history, medical history, their current knowledge of their disorder, their goals, means of support, and their personal view of the impact of their disorder. This information is vital to forming an accurate diagnosis as well as to guiding management recommendations and creating an appropriate intervention plan. Patient reports also take many different forms, ranging from informal patient interviews to standardized questionnaires, such as the Eating Assessment Tool (EAT-10) (Cheney, Siddiqui, Litts, Kuhn, & Belafsky, 2015).

Non-instrumental evaluations and observations also play key roles in assessment. These evaluation measures are typically performed by the clinician and commonly consist of non-standardized procedures such as oral motor exams, speech tasks, and clinical bedside swallow evaluations. Non-instrumental assessments provide the clinician with information relating to the

nature and cause of dysphagia, as well as information regarding the patient's current abilities. Clinicians then use this information to form hypotheses regarding the patient's physiology. This information is important as management recommendations are often based on correcting the underlying physiological difficulty. For some patients, this provides sufficient information, and treatment recommendations can be made at this stage. However, other patients may require additional forms of assessment.

Instrumental evaluations are used when the information acquired through other forms of assessment is insufficient, and a more detailed view of specific aspects of swallow physiology is necessary to provide effective dysphagia management. For this study, only videofluoroscopic swallow studies (VFSS) will be examined in detail, as this was the only form of instrumental evaluation used.

Videofluoroscopic swallow studies (VFSS) are x-ray imaging procedures which enable clinicians to observe internal oral, pharyngeal, and laryngeal structures while the patient is swallowing. This form of instrumental assessment is currently one of the most commonly used assessments in clinical practice (Krisciunas, Sokoloff, Stepas, & Langmore, 2012). However, there are mild risks associated with the procedure. X-ray beams are a form of high-energy radiation and radiation may damage both bodily tissues, and DNA. As these effects are cumulative, clinicians must always limit their patients' exposure and rely on clinical judgment when recommending these tests (Smith, 2012). Additionally, patients are not always appropriate for this form of testing, as successful completion requires patients to follow instructions accurately as well as sit or stand upright independently. Given that many patients with dysphagia are either hospitalized or have complex medical comorbidities, this form of assessment is not always feasible or appropriate (Ward, 2009).

For patients who can undergo this form of assessment, the information obtained is extremely valuable. Videofluoroscopic films permit observations of internal structures during the swallow, meaning that clinicians can use videofluoroscopic films to observe biomechanics, ideally identifying or ruling out physiological causes of dysphagia. These studies also provide clinicians with opportunities to test the efficacy of different compensatory treatment strategies. Also, the videos created by videofluoroscopic swallow studies may be analyzed to obtain quantitative values that clinicians and researchers may use to guide both patient management and contribute to clinical science. Many different protocols have been established for this type of analysis; some are favored by clinicians and others by researchers. This paper will focus on three specific measures used to analyze videofluoroscopic video, as these measures were used in this study.

First, Rosenbek, Robbins, Roecker, Coyle, and Wood (1996) developed a penetration-aspiration scale which is useful to both researchers and clinicians as the scale quantifies the severity of airway infiltration during the swallow, along eight ordinal points. Specifically, the scale identifies the depth to which material penetrates the larynx/ airway, any presence of laryngeal or tracheal residue post swallow, and whether an overt reflexive response occurs to clear material through the assignment of numerical values. In this way, the scale provides an estimate of the risk that respiratory tissue exposure to swallowed material that has entered the airway may cause adverse respiratory system outcomes. However, the scale does not quantify the timing or amount of material aspirated/ penetrated (Rosenbek et al., 1996). Therefore, clinicians must use other analysis measures to add this information to their analysis.

One type of measure which may be used is a pharyngeal retention scale, such as the one developed by Eisenhuber et al. (2002) after adapting work from Perlman et al. (1989). Their scale consists of a three-points scale and is used to measure post–swallow residue in the valleculae and

pyriform sinuses. Scale values range from one to three, and numbers correspond to the estimated height of the area of residue within a given cavity, using the height of the anatomical cavity (valleculae, pyriform sinuses) as the reference. In this way, the pharyngeal retention scale allows clinicians and researchers to quantify the pharyngeal residue a patient may exhibit in a standardized way. As a result, this scale may be used to document patient progress as well as to research the different factors impacting residue retention. However, one drawback of this scale is that the lowest score comprises "0-25% height of the residue column" and does not distinguish between a thin coating of barium with an anatomical cavity and residue filling up to 25% of the cavity. This drawback could potentially limit the scale's sensitivity, i.e. the scale's ability to detect meaningful change, particularly in patients with less severe pharyngeal retention. Lof and Robbins (1990) used a three-point scale that accounted for "no visible residue" and "coating" of residue, a one-dimensional line of residue seen on the mucosal surface after the swallow. To remedy this drawback, we combined these scales to include the addition of a zero value to the scale to differentiate between no visible residue and a one-dimensional, thin layer of residue coating, resulting in a five-point scale (see Table 6, 2.7 Measurement, pg. 42). This modified version of the pharyngeal retention scale was used in this study.

However, not all videofluoroscopic analysis measures consist of scale scores. For example, kinematic durational measures may also be taken. The original protocol for conducting kinematic durational measures was created by Logemann, Kahrilas, Begelman, Dodds, and Pauloski (1989), whose work has provided foundational knowledge regarding swallowing function and patient responses to treatment in a diverse range of patient populations. The protocol consists of identifying specific kinematic swallowing events and analyzing the relationships among them. Their protocol was further refined by Lof and Robbins (1990), who also compared frame numbers

on the VFSS videos, and then calculated the timing of swallowing events based on frame numbers. Both methodologies are still widely in use today. Kinematic analysis has been used to establish norms for patient populations regarding specific swallowing patterns, including oral transit durations, pharyngeal transit durations, upper esophageal sphincter opening durations among others. Today, kinematic analysis is primarily used by researchers to quantify patterns of improvement or regression by comparing values found in patients with dysphagia to norms established in healthy patient populations.

In summary, dysphagia assessment is multi-dimensional, necessitating the use of many different forms of evaluation. This necessity is due to the strengths and weaknesses of different evaluation forms, as each provides different information to the clinician. Therefore, health care providers must use their clinical judgment to ensure they are providing the best assessments available for their individual patients.

1.3.3 Dysphagia treatment

Dysphagia treatment must also be individualized to the patient. One way clinicians approach this is by customizing intervention using two different types of techniques, compensatory and restorative. Compensatory techniques rely on principles of biomechanics and the physics of fluid flow to optimize bolus transfer and airway protection. Commonly used techniques include posture alterations, such as lateral head flexion (head tilting) or rotation (head turning), and modifications to bolus volume (small bites and sips) and viscosity (thickening) (Cabib et al., 2016). In contrast, rehabilitative or restorative techniques are designed to produce an enduring change in swallowing physiology over time (Cabib et al., 2016), and are best for patients who may improve. Commonly used techniques include stimulation techniques and exercise. Stimulation techniques, in particular,

thermotactile and electrical stimulation techniques, have recently regained increased clinical interest although more evidence of efficacy is currently needed (Christiaanse et al., 2011). Contrastingly, exercise rehabilitative techniques currently have the greatest empirical support within the dysphagia literature, particularly regarding strengthening exercises (Carnaby-Mann, Crary, Schmalfuss, & Amdur, 2012; Fujiu & Logemann, 1996; Robbins et al., 2005; Rogus-Pulia et al., 2016; Wada et al., 2012). These exercises will be the focus of this study.

1.3.4 Exercise overview

As exercise rehabilitative techniques have strong support in the dysphagia literature (Carnaby-Mann et al., 2012; Fujiu & Logemann, 1996; Robbins et al., 2005; Rogus-Pulia et al., 2016; Wada et al., 2012), clinicians should obtain a basic understanding of exercise science. Cooper et al. (1999), defines exercises as "planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness" (p. 143). Garber et al. (2011) clarify this by defining the five most important aspects of physical fitness as cardiovascular endurance, body composition, flexibility, muscular strength, and muscular endurance. This paper will focus on muscular strength training, as this form of exercise was the primary focus of this study.

The most common form of muscular strength training involves exercises with the addition of external resistance, called resistance training (Garber et al., 2011). In resistance training, muscular exercise occurs via muscular contractions which may be divided into two categories, static and dynamic. Static, or isometric contractions, occur when a muscle generates force without changing length (Garber et al., 2011). Dynamic muscle contractions occur when a muscle generates force while either lengthening (eccentric) or shortening (concentric) (Garber et al., 2011).

Other important aspects of resistance training include variations in intensity, load, volume, repetition, and timing (American College of Sports Medicine, 1998). When targeting strength, the American College of Sports Medicine recommends that strength training should be completed on at least two non-consecutive days each week, with a volume of one to three sets of eight to 12 repetitions for healthy adults (American College of Sports Medicine, 1998). Also, a rest period of two to three minutes should occur between sets for higher intensity exercises that use heavier loads, and one to two minutes rest should occur between lower intensity exercises with light loads. The load, or intensity, of the workout, should consist of 60-70% muscle group current maximum strength for novice to intermediate exercisers, to 80-100% for advanced practitioners (American College of Sports Medicine, 1998).

1.3.5 Muscular strength training in dysphagia therapy

Muscular strength training in dysphagia therapy has taken many different forms. For example, Shaker et al. (2002) developed a "head lift" exercise which has been shown to produce small increases in upper esophageal sphincter opening diameter and duration, although replication of these findings was inhibited due to high patient discomfort during the exercise. In contrast, Wada et al. (2014) developed a more specific mandible depression exercise that also shows promise in increasing upper esophageal sphincter opening and hyolaryngeal excursion, without high attrition rates. These exercises are both currently used in clinical practice (Krisciunas et al., 2012). Notably, the most established form of muscular strength training exercise in the dysphagia research literature was identified by Robbins et al. (1995). Here, the researchers originally identified the tongue to be of particular interest in pressure generation. Their focus, for nearly 20 years, on lingual exercise has resulted in studies demonstrating the efficacy of isometric lingual strength

training in patients following stroke (Robbins et al., 2007) and the healthy aging population (Robbins et al., 2005).

While lingual strengthening exercise protocols have established support within the dysphagia literature, exact administration of these protocols is still under debate. Specifically, some clinicians prefer to administer lingual strengthening exercise protocols using non-standardized objects for resistance, such as a tongue depressor. However, other clinicians prefer implementing strength training exercises uses specially designed and calibrated devices, referred to as device-mediated lingual strengthening protocols. Device-mediation has unique advantages in that it allows for exact measurement of exercise targets and load. In this way, using a device helps clinicians ensure that they are adhering to the American College of Sports Medicine guidelines. Device-mediation is also beneficial for the patient, as it allows for biofeedback, wherein the consumer may directly observe their target load accuracy and individually monitor their overall progress.

Today the most well-researched tool for the application of device-mediation in dysphagia treatment is the Iowa Oral Performance Instrument (IOPI) device. This device is a portable handheld tool that measures pressure using a pneumatic sensor. An air-filled balloon is placed in the mouth and compressed between the tongue and the hard palate. The sensor relays pressure information through a digital converter where it is reported in kilopascals (kPa). The original prototype was invented by Dr. Erich Luschei in 1988 (IOPI Medical, 2013). Originally, this device was intended to measure articulation-related tongue strength and endurance. However, it has since expanded to include research and practical application in both lingual strength and hand strength (Adams, Mathisen, Baines, Lazarus, & Callister, 2013).

1.3.6 Efficacy studies

Support for the use of lingual strengthening exercise is strong within the dysphagia research literature, particularly concerning patients with conditions such as normal aging, and stroke (Adams et al., 2013). In healthy older adults, participants treated with an Iowa Oral Performance Instrument (IOPI) device achieved significant increases in tongue strength as well as overall tongue bulk (Robbins et al., 2005). Older adults treated with an Iowa Oral Performance Instrument (IOPI) device also showed less restrictive diets, less perceived effort during swallows, an improvement in overall quality of life, and decreases in both hospitalizations and pneumonia diagnoses when compared to controls who did not receive device-mediated treatment (Rogus-Pulia et al., 2016). Regarding patients post stroke, research has shown that patients treated with an Iowa Oral Performance Instrument (IOPI) device gained an increase in isometric lingual strength, swallowing pressure when compared to baseline (Robbins et al., 2007).

Notably, all of the studies above used device-mediation when administering lingual strengthening exercise. To date, very little research exists regarding the efficacy of more informal tools used for resistance such as tongue depressors. The only study examining this issue, known to the principal investigator (NB), was published by Lazarus and colleagues (2003). This study examined the efficacy of two different methods of administration of lingual strengthening exercise and compared both to a "no exercise" control group. Results demonstrated that lingual strengthening exercise, regardless of method of administration, causes a significant increase ($p=.04$) in maximum tongue strength, as measured by an Iowa Oral Performance Instrument (IOPI) device. Results also revealed that there was no difference between the two groups in tongue strength post-baseline. These results indicate that both device-mediate

exercise and informal resistance applicators have the same efficiency. However, as this study has not been replicated, further research needs to be conducted regarding this issue.

Another paucity in the research literature regarding lingual strengthening exercise concerns diverse patient populations. While patients with dysphagia due to healthy aging and stroke have demonstrated benefits following lingual strengthening exercise treatment protocols, other patient populations have not been explored. This scarcity needs to be resolved as different patient populations present with different difficulties, needs, and concerns. Distinctiveness is particularly relevant concerning patients with head and neck cancer, as the nature of their underlying condition, cancer, and the treatment options for this condition create unique concerns.

1.4 HEAD AND NECK CANCER

Patients with dysphagia resulting from cancerous lesions in the head and neck are a unique patient population. Specifically, patients with head and neck cancer are highly variable and rarely respond to treatments in the same way (Krisciunas et al., 2012). While the current research literature is robust regarding some sources of patient variation, little is known about other aspects. These lacking areas of the research literature need to be explored with haste, particularly because of the prevalence of this disease. Head and Neck Cancer is the sixth most commonly diagnosed cancer worldwide with 635,000 people newly diagnosed each year (Nund et al., 2014). Additionally, statistical projections predict a rise in diagnosis in the near future due to the increasing incidence of human papillomavirus (HPV), which is a virus that may lead to the development of head and neck cancer (Callaway, 2011).

Given the increasing incidence and the burden of this disease, health care providers need to be able to provide effective treatments, and detailed information regarding how individuals react to different treatments is crucial to accomplishing this goal (Krisciunas et al., 2012). This study attempts to fill in these gaps by examining participant characteristics including personal demographic information and cancer-related medical history. Therefore, this paper will focus on existing literature and trends regarding these concepts below.

1.4.1 Personal demographic information

Personal demographic information is collected by all medical facilities, as it provides a basic patient profile and allows for identification. This study will focus on two specific items of patient demographic information, age, and gender, as these items were examined in relation to variations in participant improvement in this study.

In regards to gender, research has demonstrated that men are two to three times more likely to develop head and neck cancer during their lifetimes than women (National Cancer Institute, 2017). As more men are diagnosed with head and neck cancer, more research regarding this condition has been conducted on males. Therefore, less is known about how women respond to treatment. This information is imperative to providing effective services moving forward, as men and women may present with unique symptoms and react differently to treatments (Mikaeli, Farrokhi, Bishehsari, Mahdavinia, & Malekzadeh, 2006). Additionally, the rate of head and neck cancer in women has been rising for several decades (National Cancer Institute, 2017). Therefore, more research needs to be done regarding how gender impacts treatment success in patients with head and neck cancer.

Similarly, age is another patient demographic factor which requires further investigation. Specifically, the current research literature has demonstrated that people over the age of 40 have a higher risk of developing head and neck cancer (National Cancer Institute, 2017). While this information is useful to prescribing physicians, it does little to inform clinicians about how to approach treatment based on age. For example, patients diagnosed in their 40s have a significantly higher survival rate than those diagnosed in the 70s (National Cancer Institute, 2017). However, the literature has found that some older adults with head and neck cancer still experience long-term benefits from aggressive CRXT (Maggiore et al., 2013). Research literature has also demonstrated that elderly patients with head and neck cancer may have unique concerns, setting them apart from younger patients, especially involving polypharmacy, i.e. improper medication management (Maggiore et al., 2014), and toxicity (Maggiore et al., 2013). While sufficient research does not yet exist to identify those who can tolerate more intense treatments reliably, team-based approaches seem to lead to better outcomes and identification in this patient population (Maggiore, 2016).

In summary, while the research literature has strong documentation concerning the prevalence of head and neck cancer in specific patient demographic categories, very little information is currently available regarding how these characteristics impact treatment. Therefore, more research needs to be done regarding the effects of patient characteristics for clinicians to provide truly individualized services.

1.4.2 Medical history factors

A patient's medical history may also provide clues to clinicians regarding how a patient may respond to different forms of treatment. For the purpose of this study, three specific factors will

be described in detail, as these factors were the only aspects explored in this study. Specifically, this paper will delve into how tumor presentations, cancer treatments, and timing may impact patient treatment outcomes.

The first source of varied responses to treatment in patients with head and neck cancer stems from the features of cancerous tumors. Tumor presentations are heterogeneous, showing variability in size and rate of advancement. Accordingly, Pierre Denoix developed a standardized classification system for tumor severity in the 1940s, called TNM staging (Brierley, 2006). This system has since been adopted globally by physicians and health organizations such as the World Health Organization (Brierley, 2006). Today, this system is used to classify head and neck cancers worldwide. In this system, "T" refers to the size of the primary tumor, "N" refers to lymph node involvement, and "M" refers to distant metastases. Table one provides definitions of the TNM staging definitions used for patients with head and neck cancer.

Table 1: TNM staging used for patients with head and neck cancer

Staging		**Definition**
T	TX	Primary tumor cannot be assessed
	T0	No evidence of tumor
	Ti	Abnormal cells that have not spread
	T1	Tumor two centimeters or less
	T2	Tumor between two and four centimeters
	T3	Tumor greater than four centimeters
	T4	Advanced local disease
N	NX	Lymph nodes cannot be assessed
	N0	No regional lymph node metastasis
	N1	Metastasis, one ipsilateral lymph node, less than three centimeters
	N2	Metastasis, one ipsilateral lymph node, multiple ipsilateral lymph nodes, or bilateral or contralateral lymph nodes, between three and six centimeters
	N3	Metastasis in lymph node, greater than six centimeters
M	M0	No distant metastasis
	M1	Distant metastasis

(National Cancer Institute, 2016a)

Tumor staging matters for patients, as staging has been linked to survival rates (Lee et al., 2016) and may determine a patient's eligibility for treatment (Boscolo-Rizzo, Maronato, Marchiori, Gava, & Da Mosto, 2008). Treatment eligibility is also important, as different treatments have been linked with various overall outcomes, particularly concerning quality of life, due to the differences in side effects associated with different treatments (Boscolo-Rizzo et al., 2008). These differences constitute the second main factor for patient variation. Specifically, that patient outcomes vary based on the type of primary cancer treatment they received.

Currently, there are two main categories of primary cancer treatments available for patients with head and neck cancer, surgical and nonsurgical. Surgical treatment options range from minimally invasive, using endoscopic instrumentation (Goh, Ng, & Teo, 2010), to more invasive interventions such as surgical removal of the larynx (laryngectomy) or tongue (glossectomy) (Boscolo-Rizzo et al., 2008). Nonsurgical treatment options also vary, including radiation and chemoradiation therapies. These treatments destroy and inhibit cancer cells through alternative methods including x-ray technology and pharmaceuticals. These treatments will be the focus of this study.

Radiation therapy, also called external beam radiation therapy (XRT), is a nonsurgical cancer treatment which aims to eliminate and prevent cancerous tumors by destroying cells or inhibiting growth and division. Radiation therapy is implemented as both a standalone therapy and as a therapy supplement to surgical resection (National Cancer Institute, 2016b). Radiation therapy may be used on both large and small areas of the body and is usually given daily for several weeks in an outpatient clinic or treatment center (Palm & Johansson, 2007). During treatment, an x-ray machine directs one or more beams of high-energy x-rays (typically photon beams) at a patient's tumor (Palm & Johansson, 2007). Whether or not a patient received radiation therapy is

crucial information for clinicians to know, as these patients present with very specific side effects related to radiation, many of which may be caused by iatrogenic dysphagia (Lazarus et al., 1996).

Chemotherapy is a different form of nonsurgical primary cancer treatment. Instead of relying on x-ray beams, chemotherapy uses drugs to destroy, stop, or slow the growth of cancer cells (National Cancer Institute, 2016b). Chemotherapy may be used before surgery or radiation therapy to increase the success rate of planned surgical or radiation treatments (Forastiere et al., 2003), or it may be used following radiation or surgical resections to treat the risk of residual disease based on disease staging (National Cancer Institute, 2016b). Chemoradiation therapy (CXRT) refers to the combination of chemotherapy and radiation therapy. This combination is used to increase the curative effect. The theoretical basis for this use is based on the "Steel Paradigm," which was introduced by Steel and Peckham (1979). In this article, the authors posited that the two treatments enhance cancer survival rates because they are directed towards different parts of the body and work independently. Specifically, radiation acts to target localized tumors whereas chemotherapy drugs eliminate distant lesions. While the actual biological underpinnings of the combination effect of are more substantially more complex, consisting of specific interactions, this theoretical model provides a basic understanding of the enhanced therapeutic effects which may be obtained through chemoradiation treatments.

Clinicians need to know which primary cancer treatment patients received because they present with different side effects, one of which may be dysphagia. Effective dysphagia management requires this information. Additionally, treating clinicians need information regarding when these treatments were administered, as the associated side effects change over time (Logemann et al., 2008). Therefore, the third main factor which influences patient variation in

presentation and responsiveness to treatment, related to patient cancer-related medical history is how much time has elapsed since nonsurgical cancer treatment.

First, patients who had little time pass between completing nonsurgical cancer treatments, and commencing dysphagia treatment may still be experiencing the short-term side-effects of primary cancer treatments. For those who received radiation therapy, this likely includes both tissue and sensory changes, as radiation destroys diseased tissue and its microvascular supply, causing changes in adjacent tissue architecture and integrity. Short-term, acute tissue changes range from relatively mild effects such as erythema, or reddening of tissue, to extreme adverse outcomes such as osteoradionecrosis, i.e. bone death (Rogers, D'Souza, Lowe, & Kanatas, 2015). Common acute tissue conditions relating to dysphagia include xerostomia (dry mouth), mucositis (inflammation/ ulceration of mucous membranes specifically of the mouth), and desquamation (skin peeling) (Lazarus et al., 2000). Sensory changes may also occur in the short term. Patient reports indicate that dental sensations and oral/pharyngeal tactile sensations are often altered. Taste sensations may also change or become damaged (McLaughlin, 2013). Unsurprisingly, patients regularly report discomfort during meals (McLaughlin, 2013).

While these side effects are specific to radiation therapy, they may also be experienced by patients who underwent chemoradiation therapy, as this is the combination of chemotherapy and radiation treatments. Therefore, these patients may develop all of the previously discussed short-term sequelae associated with radiation therapy in addition to those associated with chemotherapy, such as fatigue, loss of appetite, fungal infections, nausea, vomiting, and pain (Kim et al., 2001). It should also be noted that the combination of chemotherapy and radiation therapy heightens the intensity of adverse sequelae associated with both radiation and chemotherapy therapy (Kim et al.,

2001). Therefore, patients who underwent chemoradiation may present differently than those who underwent radiation therapy, even though the side effects of both treatments are similar.

Long-term side effects of radiation and chemoradiation treatments may also vary from the previously discussed short-term side effects. Tissue toxicity and permanent microvascular damage are long-term effects of radiation, both in turn, lead to adverse sensory, motor, and tissue integrity outcomes. For example, soft tissue and muscle fibrosis, i.e. hardening due to devascularization (destruction or obstruction of blood vessels), is a long-term effect of radiation therapy. Fibrosis then affects both tissue compliance and sensation, even compressing nerve fibers, leading to demyelination and neuropathy (Delanian, Lefaix, & Pradat, 2012). Other serious long-term effects of these treatments include trismus, or muscle spasms of the jaw (Kraaijenga et al., 2015), vascular changes such as damage to arteries, arterioles, and capillaries (Yusuf, Sami, & Daher, 2011), and radiation-induced bulbar palsy (Shapiro, Rordorf, Schwamm, & Preston, 1996). Additionally, people who underwent chemoradiation therapy may also experience these long-term side effects. However, these patients may experience additional effects as well such as hormone irregularities, due to thyroid damage, difficulties with memory, and peripheral neuropathy (nerve damage), as these conditions have been shown to be long-term side effects of chemotherapy (Kim et al., 2001).

As substantial variation exists between the long-term and short-term side effects of nonsurgical primary cancer treatments, there is also substantial variation in how patients who underwent these treatments present. Therefore, clinicians need to keep these differences in mind when planning intervention, particularly when planning for dysphagia management. However, knowing the side effects of nonsurgical primary cancer treatment is not enough. Clinicians treating dysphagia also need to know specific information regarding how these side effects influence each patient's swallowing function.

1.4.3 Dysphagia in patients with head and neck cancer

As previously discussed, patients with radiation/ chemoradiation-induced dysphagia are a heterogeneous patient population. While the observed clinical signs of dysphagia are diverse and vary based on many factors (Krisciunas et al., 2012), some clinical signs have been consistently demonstrated by patients. These signs include increases in pharyngeal retention/ residue as well as increases in penetration and aspiration events (Lazarus et al., 2000; Logemann et al., 2008). These patterns of swallowing dysfunction following nonsurgical cancer treatment are directly linked to difficulties with pressure generation and maintenance and may be broken down by swallowing phase.

In the oral phase, decreases in pressure generation and maintenance are due to impairments in tongue range of motion and strength. These deficits then lead to poor oral transit and posterior oral valving (Lazarus et al., 2000). The resulting reduction in the generation and maintenance of intrabolus pressure then creates trickle-down effects such as pharyngeal retention/ residue and reduced airway protection due to the interdependent nature of swallow biomechanics.

In the pharyngeal phase, patients with radiation/ chemoradiation-induced dysphagia often present with impaired hyolaryngeal excursion (both superior and anterior), delays in the initiation of the pharyngeal motor response, reduced laryngeal closure, reduced epiglottic inversion, and reduced pharyngeal constriction. These changes further reduce the already diminished intrabolus pressure generation and maintenance, further compounding the effects noted in the oral phase (Logemann et al., 2008).

The esophageal phase of the swallow in this patient population is marked by reduced upper esophageal sphincter opening diameter and duration (Logemann et al., 2008). Decreases are due to both tissue changes, such as reductions in pliability, and the previously mentioned decreases in intrabolus pressure.

While these patterns have been observed in many patients with radiation/ chemoradiation -induced dysphagia, it is important to keep in mind patient variability. Therefore, clinicians should always be aware that while these patterns are common, they may not be present in all patients. As a result, dysphagia management must be individualized to be effective.

1.4.4 Current treatments for radiation/ chemoradiation-induced dysphagia

Unfortunately, there is little consensus in the field today regarding how best to individualize treatment (Krisciunas et al., 2012). In fact, there is little consensus in the field regarding best practices for even approaching dysphagia treatment in this population (Krisciunas et al., 2012). Perhaps this lack of consensus explains why much of the recent emerging literature emphasizes treatment batteries, containing multiple exercises, instead of individualized intervention plans.

For example, in Virani (2015), researchers examined the effectiveness of a dysphagia treatment battery consisting of three different exercises specifically aimed to strengthen muscles involved in tongue retraction, hyolaryngeal excursion, and pharyngeal constriction. These exercises included sustained head-lifts (Shaker et al., 2002), dry swallows with a tethered tongue (Fujiu & Logemann, 1996), and pharyngeal squeeze (Fuller, Leonard, Aminpour, & Belafsky, 2009). Patients who received the exercise-based therapy saw an increase in oral intake and a decrease in feeding tube dependence when compared to those who did not receive exercise-based

therapy. This study suggests that exercise therapy protocols can have a positive effect on outcomes for patients with radiation/ chemoradiation-induced dysphagia.

A similar study was conducted by Hutcheson et al. (2013) and reported similar findings. However, this study used a different exercise protocol. Specifically, the experimental exercise protocol consisted of many varied tasks including head-lifts, lingual protrusion/ retraction, jaw stretches, effortful swallows, falsetto, yawn, gargle, and intentional vocal fold closure before swallowing with or without bearing down. Patients who received this exercise treatment experienced more positive results when compared to those who did not receive exercise treatment, as defined by greater oral intake and less feeding tube dependence.

Another similar study was conducted by Carnaby-Mann et al. (2012), who developed a different exercise program called "Pharyngocise." This protocol consisted of tongue press, falsetto, hard swallow, and jaw resistance/strengthening exercises. This study examined the effectiveness of this treatment by comparing the performance of patients who completed this exercise program to patients who received "usual care" and patients who received a "sham swallowing intervention." The researchers found that patients who completed the "Pharyngocise" protocol experienced less musculature deterioration than those who completed the "usual care" protocol or "sham swallowing intervention." Additionally, those who completed the "Pharyngocise" protocol experienced better overall functional swallowing abilities including, mouth opening, chemosensory acuity, and salivation rate, than participants who completed other protocols.

Interestingly, this study was the only one to include lingual strengthening exercises. This observation was surprising as vertical lingual compression strength is a major contributor to both pressure generation and maintenance (Lazarus et al., 2003). As patients with radiation/

chemoradiation-induced dysphagia typically present with decreases in airway protection and increases in pharyngeal retention, it is logical to conclude that patients with radiation/ chemoradiation-induced dysphagia could potentially benefit from lingual exercise, as both of these patterns have been shown to be remediated by vertical lingual compression strength in other patient populations (Robbins et al., 2005; Robbins et al., 2007). Therefore, the absence of lingual strengthening exercises should be noted.

Additionally, it should be noted that while Carnaby-Mann et al. (2012) did include lingual strengthen exercise, the authors did not describe specific details regarding the protocols used, e.g. whether administered via IOPI or a tongue depressor. Also, the effectiveness of the exercise program was tested as a single unit. Therefore the individual contributions of exercises could not be isolated. This lack of isolation is problematic, due to the variability of patient needs present in this patient population. Therefore, while the inclusion of this target was warranted, the specific contribution of lingual strengthening exercise still needs to be explored.

Notably, a study by Lazarus (2014) examined the specific contributions of lingual strengthening exercise in patients with radiation/ chemoradiation-induced dysphagia, by comparing the performance of patients treated with lingual strengthening exercise via tongue depressor to a control group which did not receive lingual strengthening exercises. At the end of the six-week treatment period, no differences were observed between groups in tongue strength, measured via an Iowa Oral Performance Instrument (IOPI) device, oropharyngeal swallow efficiency (Rademaker, Pauloski, Logemann, & Shanahan, 1994), or patient-reported quality of life (Funk, Karnell, Christensen, Moran, & Ricks, 2003). The authors attributed these results to poor patient adherence levels and a short therapy period (Lazarus et al., 2014).

Another possible contribution to the null results could be related to the exercise protocol used in the study. This protocol consisted of ten repetitions per practice session, five practice sessions per day, five days a week for six weeks. While the researchers stated that this protocol was based on guidelines provided by the American College of Sports Medicine, no citation was provided. This oversight is troubling as their protocol varied considerably from other researched protocols and conflicts with other recommendations for strength training given by the American College of Sports Medicine (American College of Sports Medicine, 1998). This organization recommends that strength training exercises use high intensity/training resistance levels (defined as 75% - 90% maximal resistance), eight to 12 repetitions per set, with workouts occurring two to three days per week (American College of Sports Medicine, 1998). Given the disparities between implemented and recommended protocols, it is possible that the paucity of evidence regarding lingual strength training after radiation therapy could be attributable to methodological flaws in the implementation of the exercise intervention.

The successful application of the American College of Sports Medicine recommended strengthening protocols for other dysphagia patient populations lends support to this claim. For example, Robbins (2005), used Iowa Oral Performance Instrument (IOPI) devices with all participants. In this way, accurate readings of lingual strength could be obtained for each participant throughout the study. Also, the Iowa Oral Performance Instrument (IOPI) device allowed for the establishment of high intensity/ training resistance levels, as researchers could target specific exercise goals during each session. The researchers took advantage of measurement precision enabled by device-mediation and based goals on recommendations from the ACSM and measurements of participants' baseline maximal lingual strength (60% or 80%). Maximal lingual strength was then recalculated at the end of the second, fourth, and sixth weeks of exercise

(Robbins et al., 2005). In this way, the researchers could ensure that the exercises were using the principles of progressive resistance. This study also asked participants to complete three sets of 10 repetitions, three times per day, three days per week, by the recommendations for strength training provided by the American College of Sports Medicine (American College of Sports Medicine, 1998). Also, Robbins (2005) also used a longer treatment period of eight weeks, vs. the six-week period of Lazarus (2014). Interestingly, the authors of Lazarus (2014) did not provide a reason for this shortened therapy time frame. As significant improvement for strength training was seen at four weeks, and even greater improvement was seen in eight weeks, this longer treatment period may have positively influenced outcome measures (Kays & Robbins, 2006). These methodological modifications in the deployment of the exercise protocol seem to have significance as seen by strong positive outcomes. Especially since all subjects showed an increase in lingual strength, swallowing pressures, and in a subset of their participants, increases in overall lingual volume as measured via MRI (Robbins et al., 2005). Given these results, the application of a strength based isometric lingual exercise protocol warrants further investigation in patients following radiation/ chemoradiation treatments, as strength based lingual exercise protocols have not yet been demonstrated to be beneficial for patients with head and neck cancer.

1.5 RESEARCH QUESTIONS

To date, treatment information for patients with radiation/ chemoradiation-induced dysphagia is limited. Specifically, the contributions of individual exercises to dysphagia rehabilitation remain unknown, particularly the contributions of device-mediated lingual strengthening exercises. Also, links between participant characteristics and treatment success are also unknown. This

study aims to address these deficit areas by describing the experiences of six individual participants with radiation/ chemoradiation-induced dysphagia. The aims of this study are listed below:

AIM 1: to explore the effectiveness of the addition of a device-mediate lingual strengthening exercise protocol to "standard dysphagia therapy" by describing participant improvements in swallowing function through measures of airway protection and pharyngeal retention.

Research Question 1: Do participants who complete a device-mediated lingual strengthening exercise protocol in addition to "standard dysphagia therapy" demonstrate more improvement in swallowing function (measured by airway protection and pharyngeal retention) than participants who only complete the "standard dysphagia therapy" treatment protocol?

AIM 2: to explore whether patients with specific characteristics benefit most from this type of treatment.

Research Question 2: What patient characteristics are shared by participants who show improvement (benefits) from dysphagia treatment (both "standard dysphagia therapy" and "standard dysphagia therapy" plus device-mediated lingual strengthening exercise)?

It should be noted that these aims are a departure from the original aims of this study. Initially, this study aimed to investigate the effects of a device-mediated lingual strengthening exercise protocol on overall swallowing function as measured by seven kinematic durational measures in addition to measures of airway protection and pharyngeal retention. However, following the completion of data collection and primary analysis, the researchers chose to

remove the seven kinematic durational measures from this thesis study. Instead, these measures would be examined in more detail in the larger study. This decision was made for study feasibility, due to the limited timeline available for masters thesis research.

2.0 METHODS

For this study, a single-subject descriptive approach was used to analyze measures of airway protection and pharyngeal retention through a secondary examination of videofluoroscopic data. Descriptive data was also obtained regarding participant characteristics. All data was collected from the initial six participants of a larger ongoing prospective experimental study. This larger study examined treatment outcomes associated with the addition of device-mediated (IOPI) isometric lingual exercise therapy protocol to "standard dysphagia therapy" (clinician-directed) treatment in patients with radiation/ chemoradiation-induced dysphagia. Appendix A details the methods used in the larger ongoing study.

2.1 ETHICS

The University of Pittsburgh Institutional Review Board approved the larger ongoing study, and all of the analyses performed in this study, on October 21, 2015 (PRO15080566). The principal investigator of this thesis study was added as a member of the larger IRB approved study team, with the role of analyzing videofluoroscopic data, on July 8, 2016.

2.2 STUDY DESIGN AND DESCRIPTION

A pre-post single-subject design was used for this study; wherein each participant was examined individually. Measures of airway protection and pharyngeal retention were obtained for each

participant via videofluoroscopic data. Videofluoroscopic data was collected at the pre-dysphagia treatment stage, after which participants were assigned to groups (control or experimental). Participants assigned to the control group completed a "standard dysphagia therapy" protocol and participants assigned to the experimental group completed a "standard dysphagia therapy" protocol and a device-mediated lingual strengthening exercise protocol. Videofluoroscopic data collection was then repeated at the post-dysphagia treatment stage. Following completion of the study, the principal investigator (NB) was given information regarding participant characteristics.

It is important to note that participant group assignments, videofluoroscopic data collection, and dysphagia treatment protocols were designed and completed by researchers in the larger ongoing study. Brief descriptions of their methodology are included below; detailed information is listed in Appendix A.

2.3 PARTICIPANTS, GROUP ASSIGNMENTS

This study was comprised of the first six participants who completed the larger ongoing study (See Appendix A for details regarding participant recruitment and group assignment). Three participants were assigned to the control group (by the larger ongoing study) and completed the "standard dysphagia therapy" protocol. The remaining three participants were assigned to the experimental group (by the larger ongoing study) and completed the "standard dysphagia therapy" protocol in addition to a device-mediated lingual strengthening exercise protocol.

2.4 TREATMENT PROTOCOLS

2.4.1 "Standard dysphagia therapy" treatment protocol

The "standard dysphagia therapy" treatment protocol consisted of individual intervention plans and were not standardized across subjects. Specifically, each participant was prescribed an individually tailored intervention plan by clinicians working at a tertiary teaching hospital. All intervention strategies other than isometric lingual exercise were considered for inclusion into each participant's "standard dysphagia therapy" intervention, including compensatory postures, texture modifications, and strengthening exercises targeting other dysphagia related muscle groups. All participants, regardless of group assignment, completed the "standard dysphagia therapy" protocol. For participants assigned to the control group, "standard dysphagia therapy" was the only treatment protocol completed. Contrastingly, participants assigned to the experimental group completed "standard dysphagia therapy" in addition to a device-mediated lingual strengthening exercise protocol.

It should be noted that the principal investigator of this thesis study (NB) did not have access to information regarding prescribed intervention plans until the study was completed. At this time, it was discovered that not all of the clinicians followed the guidelines for the "standard dysphagia therapy" protocol. Specifically, three participants received lingual strengthening exercises (administered via tongue depressor) as part of their "standard dysphagia therapy" intervention plans. The exercises included each participant's "standard dysphagia therapy" protocols are listed below in Table 2.

Table 2: Exercises prescribed in "Standard dysphagia therapy"

Participant (Group)	Exercises Prescribed in "Standard Dysphagia Therapy."
A (Experimental)	None prescribed
B (Control)	Lingual strength via tongue depressor x15
	Lingual strength via finger to cheek x15
	Masako x10-15
	Effortful swallow
	Mendelsohn maneuver x10
C (Experimental)	Mandibular range of motion
	Masako x10
	Effortful swallow
D (Control)	Mandibular range of motion x10-15
	Lingual range of motion x10-15
	Masako x10-15
	Effortful swallow x10-15
	Base of tongue retraction x15
E (Experimental)	Effortful swallow x10-15
	Mandibular depression x10-15
	Lingual strength via tongue depressor (added week 3)
F (Control)	Lingual strength via tongue depressor (unknown repetitions)
	Masako x15
	Mandibular depression x15
	Mandibular range of motion x15
	Effortful swallow

2.4.2 Device-mediated lingual strengthening exercise protocol

In addition to "standard dysphagia therapy" interventions, those in the experimental group completed a device-mediated lingual strengthening exercise protocol. Using the Iowa Oral Performance Instrument (IOPI), participants performed three sets of ten "press" repetitions daily, on three nonconsecutive days each week, over an eight-week period. Unique exercise targets were set for each participant, based on assessment strength measures completed by the clinicians

according to the protocols of the larger ongoing study (See Appendix A for assessment methods), following the methods of Robbins et al. (2005). Based on these methods, 60% of maximal isometric strength was the exercise target for the first week of treatment, which increased to 80% for weeks two through eight. At the beginning of weeks three, five, and seven, maximum pressures were re-measured, and each participant's 80% target was recalculated based on their new maximum pressure generation. Table 3 below displays the exercise target valuation schedule.

Table 3: Exercise treatment timeline

Exercise Treatment Timeline	**Target Goal (% of baseline isometric maximal strength)**
Week 1	60%
Week 2	80%
Week 3	Recalculate max; 80% of new max
Week 5	Recalculate max; 80% of new max
Week 7	Recalculate max; 80% of new max

(Robbins et al., 2005)

2.5 VIDEOFLUOROSCOPIC DATA COLLECTION

Videofluoroscopic data collection was performed by clinicians employed at a tertiary teaching hospital, including the principal investigators of the larger ongoing study. Data collection was conducted according to the experimental protocols used in the larger ongoing study detailed in Appendix A. During videofluoroscopy, clinicians had participants swallow an assortment of textures and volumes of contrast using a variety of patient postures. However, not all texture-volume-posture combinations were analyzed in this study. Only descriptions of the swallow conditions analyses used in this study are listed below.

As the aim of this study was to examine the effects of lingual strengthening exercise and not swallow conditions, only two consistency/texture conditions, two delivery devices, and one patient posture condition were included for analysis. The two consistency/texture conditions included were Varibar Thin Liquid at less than five centipoise viscosity and Varibar Pudding-thick at 5000 centipoise viscosity. The two delivery devices referred to the method of bolus delivery to the participant and included spoon or cup. Spoon-administered thin liquid boluses were approximately three mL volume, and the volume of cup-administered thin liquid boluses was self-selected by each participant and ranged from approximately five milliliters to 20 milliliters. Spoon administered pudding boluses were approximately 15 milliliters. In regards to patient posture, all swallows analyzed within this study featured neutral patient posture, meaning that no swallows featuring compensatory postures (such as a chin tuck or head turn) were included.

For this study, all swallow conditions were represented in three texture- volume – posture combinations, which are listed below in Table 4. Numerical category codes were created for swallow condition combinations before data measurement and analysis. Each swallow condition featured three numbers which related to specific features. For example, the first digit related to the delivery device, the second to consistency/ texture, and the third to posture. Table 4, listed below, decodes the numerical swallow condition codes used in this study.

Table 4: Description of swallow conditions

Swallow Condition #	Device	Consistency/ texture	Posture
111	Spoon	Varibar Thin Liquid	Neutral
211	Cup	Varibar Thin Liquid	Neutral
4141	Spoon	Pudding-thick	Neutral

2.6 VIDEOFLUOROSCOPIC DATA MANAGEMENT

All videofluoroscopic videos were de-identified (all participant identifying information was removed) at the time of recording using a bypass function within the Foresight Imaging TIMS Medical DICOM system (Foresight Imaging, 2016). Videofluoroscopic digital videos were then converted into PicVideo MJPEG Codec files by the principal investigator (NB) using the Foresight Imaging TIMS Medical DICOM system (Foresight Imaging, 2016) in the Radiology department at UPMC Presbyterian Hospital. The PicVideo MJEPG Codec files were then duplicated to portable media. Videofluoroscopic data were then stored in digital format in the swallowing research lab in the Department of Communication Science and Disorders at the University of Pittsburgh.

2.7 MEASUREMENT

For this study, measurements of airway protection and pharyngeal retention were conducted on videofluoroscopic data. Measurements of airway protection were conducted after each swallow using the penetration-aspiration scale. Penetration aspiration scale scores were completed by the principal investigator (NB), using Image J software (Rashband & Ferreria, 2016), for all swallows according to the descriptions listed below in Table 5.

Table 5: Penetration-aspiration scores

Penetration-Aspiration Scale	
1	Material does not penetrate the larynx or enter the airway
2	Material penetrates the larynx, but remains above the level of the vocal folds, and is ejected
3	Material penetrates the larynx, remains above the level of the vocal folds, and is not ejected
4	Material penetrates the larynx, contacts the vocal folds, and is ejected
5	Material penetrates the larynx, contacts the vocal folds, and is not ejected
6	Material penetrates the larynx, passes below the level of the vocal folds, and is ejected
7	Material penetrates the larynx, passes below the level of the vocal folds, effort is made to eject material. However, the material is not ejected
8	Material penetrates the larynx, passes below the level of the vocal folds, and no effort is made to eject material

(Rosenbek et al., 1996)

Measurements of pharyngeal retention were conducted by the principal investigator (NB), using an adapted pharyngeal retention scale. This modified scale was created by Dr. James L Coyle, a dysphagia specialist, and Atsuko Kurosu, a Ph.D. candidate specializing in dysphagia, based on methodology published by Eisenhuber et al. (2002) and Lof & Robbins (1990). The scale consists of five values. Each scale value describes the height of the two-dimensional column of residue present in each cavity (valleculae and pyriform sinuses) which was measured using the line tool in the image processing software program (Rashband & Ferreria, 2016). Line segments were digitally drawn in the vertical axis at the longest point of each residue column, and the midpoint marker of the segment was used to identify the point at which the residue column exceeded 50% of cavity height. Visual inspection was used to determine whether residue exceeded 50% or 25% of cavity height. Coating was defined as a one-dimensional line of contrast on the surface of the cavity after the swallow, and “no residue” was defined as no visible contrast. These scoring criteria are pictured below in Figure 3, and detailed descriptions of the scale values are listed below in Table 6.

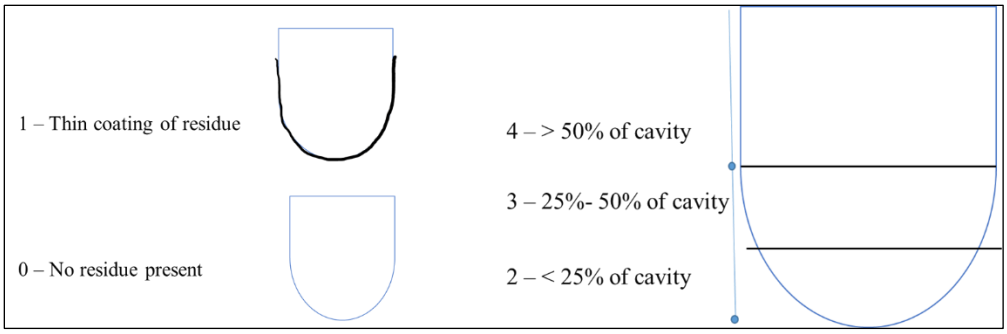

Figure 3: Visual explanation of pharyngeal retention scale alterations

Table 6: Pharyngeal retention scores

Pharyngeal Retention Scale	
0	There is no visible residue
1	The cavity is coated with a one-dimensional line of residue
2	The cavity contains an area (with height and width) of residue that occupies less than 25% of the height of the cavity.
3	The cavity contains an area (with height and width) of residue that occupies between 25% and 50% of the height of the cavity
4	The cavity contains an area (with height and width) of residue that occupies greater than 50% of the height of the cavity.

2.8 MEASUREMENT FIDELITY

Observational measures are inherently subjective and open to personal interpretation (Cicchetti, 1994). As measurements taken on videofluoroscopic data are fundamentally observational in nature, researchers must take precautionary actions to ensure measurement fidelity. For this study, concrete steps were taken to ensure measurement accuracy. These measures included researcher blinding, researcher training, and reliability testing.

2.8.1 Blinding

Before commencing measurement, the principal investigator (NB) was blinded to all identifying information regarding participants. Specifically, participant numbers, study numbers, and videofluoroscopic swallow examination dates were removed from all files by the research mentor (JLC) and files were renamed numerically using computerized random number generation before measurement. These steps were taken to blind the principal investigator (NB) from participant age, gender, tumor site, group assignment, and experimental phase ("pre" or "post" treatment).

2.8.2 Training

Before conducting measurements on the experimental data set, the principal investigator (NB) underwent measurement training at the University of Pittsburgh Swallowing Lab. Her training was conducted with her research mentor (JLC), an expert in the kinematic analysis of videofluoroscopic data (including penetration-aspiration scale scores, and pharyngeal retention scores) and a co-principal investigator on the ongoing larger experimental study. Training used de-identified videofluoroscopic images from participants in previously IRB approved studies, and consisted of demonstrations, guided instruction, performance feedback, and discussion. In total, 110 hours of training were completed including 25 hours of supervised instruction and 85 hours of individual practice. Following training, the principal investigator (NB), who performed all data analysis for this thesis, underwent testing or both intra-rater and inter-rater reliability of all measures.

Reliability testing on training data included the initial analysis of 40 swallows from non-study data on eleven kinematic events, penetration-aspiration scale scores, and pharyngeal retention scores. Computerized random number generation was then used to selected 50% of the 40 swallows, which were then re-scored by an expert judge (JLC). These results are listed below in Table 7.

Table 7: Initial inter-rater reliability results (training data)

Measures	ICC Result	Description
Kinematic Events	.99-.98	Excellent
PAS	.918	Excellent
PRS (pyriforms)	.684	Poor
PRS (valleculae)	.85	Good

Some inconsistencies were found. These were then resolved through consensus between the principal investigator (NB) and the expert judge (JLC). After reaching agreement, training data swallows were then re-scored by the principal investigator, and inter-rater reliability was then re-calculated as described above. These results are listed below in Table 8.

Table 8: Inter-rater reliability results following consensus (training data)

Measures	ICC Result	Description
Kinematic Events	.99-.98	Excellent
PAS	.994	Excellent
PRS (pyriforms)	.943	Excellent
PRS (valleculae)	.948	Excellent

The principal investigator (NB) then used computerized random number generation again to select a different 50% of the 40 swallows to establish intra-rater reliability. Statistical analysis for reliability consisted of Intra class correlation coefficient (ICC) calculations, made using IBM SPSS Statistics 23. Determinations of "excellent," "good," "fair," and "poor" reliability were

made according to the guidelines established by Cicchetti (1994). These results are listed below in Table 9.

Table 9: Intra-rater reliability testing results (training)

Measures	ICC Result	Description
Kinematic Events	.99-.98	Excellent
PAS	.994	Excellent
PRS (pyriforms)	.943	Excellent
PRS (valleculae)	.948	Excellent

2.8.3 Reliability testing (experimental data set)

Both inter-rater reliability and intra-rater reliability were also established on the experimental data set. Reliability was accomplished by randomly selecting ten percent of the data (ten swallows) to re-score all measures. Randomization was accomplished via computerized random number generation. Ten swallows were then rescored by the research mentor (JLC), to establish inter-rater reliability. A different randomly selected ten swallows were then rescored by the principal investigator (NB), to establish intra-rater reliability. Statistical analysis for reliability testing on the experimental data set used the same protocol as establishing reliability on training data, specifically ICC calculations and descriptive determinations according to values published by Cicchetti (1994). Reliability testing results from the experimental data set are listed below in Table 10 (inter-rater reliability) and Table 11 (Intra-rater reliability).

Table 10: Inter-rater reliability testing results (experimental data set)

Measures	ICC Result	Description
Kinematic Events	.94-1	Excellent
PAS	.970	Excellent
PRS (pyriforms)	.836	Good
PRS (valleculae)	.913	Excellent

Table 11: Intra-rater reliability testing results (experimental data set)

Measures	ICC Result	Description
Kinematic Events	.98-1	Excellent
PAS	.970	Excellent
PRS (pyriforms)	.981	Excellent
PRS (valleculae)	.966	Excellent

2.9 ANALYSIS

Following measurement completion, the analysis was conducted by the principal investigator (NB). Quantitative data for airway protection and pharyngeal retention were also organized for each participant. Measurement data were then averaged across trials within condition (i.e. all trails of 111 or thin liquid boluses via spoon). Individual "pre-post" differences were found by subtracting the "post" mean value from the "pre" mean value. Participant data were also normalized to the baseline to double check determinations of "improvement" and "no improvement." Normalization used the following transformation: $"Post"\ mean\ value \div$ "Pre" $mean\ value\ (baseline) = normalized\ value$. Descriptive participant demographic data was also collected and arranged by age, gender, primary cancerous lesion location, tumor staging, and date participants completed radiation/ chemoradiation.

3.0 RESULTS

Quantitative data, i.e. measures of patient airway protection and pharyngeal retention, were obtained from 12 videofluoroscopic swallow studies (93 swallows from six participants). Specifically, data were collected from all swallows assigned to the following conditions, 111 (thin liquid via spoon), 211 (thin liquid via cup) and 141 (pudding thick via spoon). The number of swallows and measurements obtained varied by participant.

Demographic data and medical history information were obtained from all six participants, regarding age, gender, and the date they completed radiation/ chemoradiation. However, medical history information regarding primary cancerous lesion location and tumor staging could only be obtained for five of the six participants. This information is displayed in Table 12 below.

Table 12: Participant characteristics

Participant	Age	Gender	Lesion Location	Staging	Time Since CXRT
Experimental Group					
A	67	F	Not available	Not available	>1 year*
C	46	M	L tonsil	T2N2	2 months
E	65	M	Larynx	T1N2	7.5 years
Control Group					
B	62	M	R tonsil	T4N2	2 months
D	56	M	Base of Tongue	T4N2	3 months
F	52	M	R tonsil	T1N2	2 months

*exact date was unspecified

Due to the single-subject nature of this study, all data was analyzed by individual participants. Results will also be presented in this manner. Specifically, listed below are individual sections for each participant wherein quantitative results are displayed, including airway protection

measures and pharyngeal retention, followed by descriptions of different participant characteristics.

3.1.1 Participant A (experimental group)

The data set for Participant A was complete, allowing airway protection measures (penetration-aspiration scale scores) to made in all three swallow conditions, resulting in a total of eighteen average values. Mean difference values, and normalized data both revealed that Participant A only showed improvement in airway protection in one swallow condition (211, thin liquid via cup). No other improvements were noted across measures. Average values, mean differences and normalized data are listed below in Table 13.

Table 13: Penetration-aspiration scores, Participant A

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2.33	3	-.667	1.28	No
211	3.75	3	.75	.8	Yes
141	2	3	-1	1.5	No

Pharyngeal residue measures were also made for Participant A in both the valleculae and pyriform sinuses, for all three swallow conditions. Average values, mean differences and normalized data all demonstrate no improvement in pharyngeal retention between the "pre" and "post" treatment phases. Table 14 below depicts pharyngeal retention data for Participant A in the valleculae. Table 15 below illustrates pharyngeal retention data for Participant A in the pyriform sinuses.

Table 14: Pharyngeal retention scores (valleculae), Participant A

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	4	4	0	1	No
211	4	4	0	1	No
141	4	4	0	1	No

Table 15: Pharyngeal retention scores (pyriform sinus), Participant A

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	3.667	4	-.33	1.01	No
211	3.75	4	-.25	1.06	No
141	1	2	-1	2	No

In regards to participant characteristics, Participant A was a 67-year-old female. She completed radiation/ chemoradiation over one year before commencing dysphagia treatment, however the exact date she finished radiation/ chemoradiation was not provided to the principal investigator (NB). Further participant characteristic information, such as primary cancerous lesion location and tumor staging information could not be obtained for this participant.

3.1.2 Participant C (experimental group)

A complete data set was also available for Participant C. Therefore, measures of airway protection (penetration-aspiration scale scores) were completed in all swallow conditions, resulting in 18 average values. Both mean differences and normalized data revealed improved airway protection across all swallow conditions, for Participant C. These values are displayed below in Table 16.

Table 16: Penetration-aspiration scores, Participant C

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	4	1	3	.25	Yes
211	1.4	1	.4	.71	Yes
141	8	1	7	.125	Yes

Pharyngeal retention measures were completed in all swallow conditions in both the valleculae and pyriform sinus, resulting in 36 average values. Mean differences and normalized data both indicate that participant four demonstrated improvements in valleculae residue in swallow conditions 111 (thin liquids via spoon) and 211 (thin liquids via cup), but not 141 (pudding via spoon). In regards to pharyngeal retention in pyriform sinuses, Participant C improved in swallow condition 141 (pudding thick via spoon) but not in either of the thin liquid swallow conditions (111, thin liquid via spoon and 211, thin liquid via cup). Average values, mean differences, and normalized data for pharyngeal retention scale scores in the valleculae are displayed below in Table 17. Scores for the pyriform sinuses are presented below in Table 18.

Table 17: Pharyngeal retention scores (valleculae), Participant C

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2.33	2	.33	.86	Yes
211	4	3	.1	.75	Yes
141	2	2	0	1	No

Table 18: Pharyngeal retention scores (pyriform sinus), Participant C

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	1.667	2	-.33	1.19	No
211	1.6	1.8	-.02	1.125	No
141	2	.5	1.5	.25	Yes

In regards to participant characteristics, Participant C was a 46-year-old male. His primary lesion location was on the left tonsil. This lesion was identified while still in early staging (T1N2).

Participant C also completed radiation/ chemoradiation approximately two months before commencing the experimental dysphagia treatment protocol and "standard dysphagia therapy" protocol.

3.1.3 Participant E (experimental group)

The data set for Participant E was incomplete. Specifically, a measurement of airway protection could not be obtained for pudding via spoon (141) during the "post" treatment phase. Therefore, mean differences and normalized data could not be obtained for airway protection for swallow condition 141 (pudding via spoon). However, as the remaining two swallow conditions were complete, (111, thin liquid via spoon and 211, thin liquid via cup) these analyses were completed for the remaining two swallow conditions. Results from these conditions show that Participant E made no improvements in airway protection during this study. These results are listed below in Table 19.

Table 19: Penetration-aspiration scores, Participant E

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	4	5	-1	1.25	No
211	2	3.67	-1.67	1.84	No
141	1	No data	Unknown	Unknown	Unknown

In regards to pharyngeal retention, average values were obtained for all swallow conditions in both the "pre" and "post" treatment phases, resulting in 36 average values. Mean differences and data normalization revealed improvements in swallow condition 141 (pudding via spoon) in

both valleculae and pyriform sinus retention. No other improvements were noted, as listed below in Table 20 and Table 21.

Table 20: Pharyngeal retention scores (valleculae), Participant E

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2	2	0	1	No
211	2.5	2.75	-.25	1.1	No
141	4	3	1	.75	Yes

Table 21: Pharyngeal retention scores (pyriform sinus), Participant E

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2	2	0	1	No
211	2	2.25	-.25	1.13	No
141	2	1.33	.67	.67	Yes

Additionally, Participant E presented with the following characteristics. His gender was male, and he was 65 at the time of treatment. His primary cancerous lesion location was in the larynx, and he was diagnosed while in early staging, (T1N2). Notably, over seven years had elapsed between finishing radiation/ chemoradiation and commencing the experimental dysphagia treatment protocol and "standard dysphagia therapy" protocol.

3.1.4 Participant B (control group)

In regards to airway protection, average values were obtained for swallow conditions 111 (thin liquid via spoon) and 211 (thin liquid via cup) in both the "pre" and "post" treatment phases. However, the data for airway protection in swallow condition 141 (pudding thick) was incomplete, therefore mean differences and data normalization could not be completed for this swallow condition. The remaining two swallow conditions (111, thin liquid via spoon and 211, thin liquid

via cup) both indicated that improvements in airway protection were made by Participant B. Table 22, listed below, depicts airway protection results for Participant B.

Table 22: Penetration-aspiration scores, Participant B

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	5.5	5	.5	.91	Yes
211	7	5.5	1.5	.79	Yes
141	No data	7	Unknown	Unknown	Unknown

Data for pharyngeal retention measures were also incomplete. Specifically, no data was obtained in the "pre" phase for swallow condition 141 (pudding via spoon), meaning that average values and data normalization could not be conducted for this swallow condition. However, complete data was obtained for all other swallow conditions, resulting in eight average values.

Mean differences and normalized data indicate that Participant B made no improvements in valleculae residue in any of the remaining swallow conditions. In regards to the pyriform sinuses, only one improvement was noted on swallow condition 111 (thin liquid via spoon). No other improvements were found in pharyngeal retention. Table 23 and Table 24 below depict pharyngeal retention results for Participant B.

Table 23: Pharyngeal retention scores (valleculae), Participant B

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2.5	3.5	-1	1.4	No
211	3	4	-1	1.33	No
141	No data	4	Unknown	Unknown	Unknown

Table 24: Pharyngeal retention scores (pyriform sinus), Participant B

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	4	3.67	.33	.92	Yes
211	4	4	0	1	No
141	No data	4	Unknown	Unknown	Unknown

Participant characteristics for Participant B were as follows. He was a 62-year-old male, whose primary lesion location was in the right tonsil. Participant B was diagnosed having advanced tumor staging, specifically T4N2. Participant B commenced dysphagia treatment approximately two months after completing radiation/ chemoradiation.

3.1.5 Participant D (control group)

Participant D had a complete data set available for analysis. In other words, average values were obtained for airway protection measures in both the "pre" and "post" phases for all three swallow conditions. Mean differences and normalized data indicate that Participant D made improvements in airway protection on swallow condition 111 (thin liquid via spoon). However, no improvements were noted for swallow conditions 211 (thin liquid via cup) or 141 (pudding via spoon). These results are listed below in Table 25.

Table 25: Penetration-aspiration scores, Participant D

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2.5	2	.5	.8	Yes
211	3	3	0	1	No
141	1	2.33	-1.33	2.33	No

Average values were also obtained for pharyngeal retention measures in both the "pre" and "post" phases for all three swallow conditions. Mean differences and normalized data indicate that Participant D showed improvements in pharyngeal retention on swallow condition 111 (thin liquid via spoon) in both the valleculae and pyriform sinuses. However, no other improvements were noted in pharyngeal retention. Table 26 below depicts analyzed pharyngeal retention data (valleculae) for Participant D. Table 27 below depicts analyzed pharyngeal retention data (pyriform sinuses) for Participant D.

Table 26: Pharyngeal retention scores (valleculae), Participant D

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	1.5	1	.5	.67	Yes
211	1.67	2.25	-.58	1.35	No
141	2.33	1	1.33	.43	Yes

Table 27: Pharyngeal retention scores (pyriform sinus), Participant D

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	1	.5	.5	.5	Yes
211	1.33	2.4	-1.07	1.8	No
141	1.33	2	-1.67	1.5	No

In regards to participant characteristics, Participant D was a 56-year-old male. His primary cancerous lesion location was the base of tongue, and the tumor had advanced staging (T4N2). Approximately three months had elapsed between finishing radiation/ chemoradiation and commencing the "standard dysphagia therapy" treatment protocol.

3.1.6 Participant F (control group)

Participant F had an incomplete data set. Therefore, average values were obtained for airway protection measures in both the "pre" and "post" phases for two of three swallow conditions (211, thin liquid via cup and 141, pudding via spoon). However, an average value could only be obtained for the "pre" phase for the remaining swallow condition (111, thin liquid via spoon). As a result, mean differences and data normalization could only be completed for the two complete swallow condition sets (211, thin liquid via cup and 141, pudding via spoon).

Mean differences and normalized data indicate that Participant F made improvements in airway protection in swallow condition 211 (thin liquid via cup), but not swallow condition 141 (pudding via spoon). These data are listed below in Table 28.

Table 28: Penetration-aspiration scores, Participant F

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	1	No data	Unknown	Unknown	Unknown
211	3.8	1.4	2.4	.37	Yes
141	1	1	0	1	No

In regards to pharyngeal retention, data were also incomplete. Specifically, an average value could not be obtained for pharyngeal retention in the pyriform sinus in the "post" phase of swallow condition 111 (thin liquid via spoon). Therefore, calculations could not be conducted for this measure. However, all other data was complete.

Mean differences and normalized data indicated no improvements in pharyngeal retention in the valleculae across all three swallow conditions. Contrastingly, results also showed that Participant F made improvements in pharyngeal retention in the pyriform sinuses in the two swallow conditions assessed, specifically 211 (thin liquid via cup) and 141 (pudding via spoon). These results are displayed below in Table 29 and Table 30.

Table 29: Pharyngeal retention scores (valleculae), Participant F

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2	2	0	1	No
211	2.17	2.6	-.43	1.2	No
141	2.5	2.67	-.17	1.07	No

Table 30: Pharyngeal retention scores (pyriform sinus), Participant F

Condition	"Pre" Average Value	"Post" Average Value	Difference	Normalized	Improvement?
111	2	No data	Unknown	Unknown	Unknown
211	1.83	1.6	.23	.87	Yes
141	2	1.67	.33	.84	Yes

In regards to participant characteristics, Participant F was a 52-year-old male, diagnosed with a primary lesion location of the right tonsil. This participant was diagnosed while his tumor was still in early staging, specifically T1N2. Approximately 2-months had elapsed between his finishing radiation/ chemoradiation and commencing "standard dysphagia therapy" treatment.

4.0 DISCUSSION

This study is the first to describe the efficacy of a device-mediated lingual strengthening protocol in patients with radiation/ chemoradiation- induced dysphagia, as measured by airway protection and pharyngeal retention. Additionally, it is also the first study to make observations regarding specific participant characteristics that coincide with greater improvement in this patient population. While this study did not produce robust results, useful observations may still be made from the data.

4.1 RESEARCH QUESTION 1

Do participants who complete a device-mediated lingual strengthening exercise protocol in addition to "standard dysphagia therapy" demonstrate greater improvements in swallowing function (measured by airway protection and pharyngeal retention) than participants who only completed the "standard dysphagia therapy" treatment protocol?

When examining participants by group assignment, no distinct patterns of improvement were noted. More specifically, five of six participants appeared to have similar rates of improvements in airway protection regardless of group assignment. For example, Participant C and Participant B were the only participants who demonstrated improvements in all of the observed swallow conditions (notably condition 141, pudding via spoon, could not be assessed for Participant B due to incomplete data), and these participants were assigned to different groups. Specifically,

Participant C was assigned to the experimental group and received device-mediated lingual strengthening exercise in addition to "standard dysphagia therapy." Whereas, Participant B was assigned to the control group and received "standard dysphagia therapy" only. These results indicate that participants assigned to both the experimental group and control group could experience similar levels of improvements in airway protection.

This observation was further supported by the remaining participants' performance. Specifically, the two remaining control group participants, Participant D, and Participant F, only demonstrated improvements in airway protection on one swallow condition. Similarly, Participant E (experimental group) also only showed improvement in one swallow condition. Once again, the grossly equivalent performance of participants in different groups indicated that both experienced similar rates of improvement.

Analysis of pharyngeal retention measures demonstrated similar results in the same five participants. Two members of the control group, Participant F and Participant D, presented with improvements in six of nine conditions. One member of the experimental group, Participant C, did as well. The last member of the control group, Participant B, presented with improvements in one of five observations, and Participant F of the experimental group presented with two of six, similar values.

Given the relatively balanced nature of the improvements made by the previously mentioned five individuals, we cannot conclude that device-mediated lingual strengthening exercise confers greater benefits than "standard dysphagia therapy" alone. However, other factors may have contributed to these results. First, the principal investigator (NB) did not have access to any information regarding patient compliance. Given that reduced treatment adherence has been demonstrated in this patient population (Lazarus et al., 2014; Logemann et al., 2008), this factor

is impossible to rule out. Additionally, missing data limited analyses for four participants. Therefore readers should use caution when interpreting these results, as they might not be fully representational of actual participant performance. Last, confounding may have played a role in creating these results as well, as most of the participants in the control group received lingual strengthening exercises comparable to those received by the experimental group.

Interestingly, confounding, due to prescribed exercises, opened the doors for an exciting comparison. Current literature demonstrates that lingual strengthening exercises administered via tongue depressors may achieve similar results to fancier device-mediated forms of the exercise (C. Lazarus, J. A. Logemann, C. F. Huang, & A. W. Rademaker, 2003). Our findings reflect these previously published results, as no distinct differences were noted between participants who completed the device-mediated lingual strengthening protocol and those who completed lingual strengthening exercises administered via tongue depressor as a part of their "standard dysphagia therapy." In this way, this study inadvertently allowed for replication of this concept in patients with head and neck cancer, enabling findings to contribute to a lacking area of the research literature. This contribution could also prove to be significant, given the current high costs of health care in this country. However, since this study was limited and not an exact replication, and the sample was very small, further research needs to be done to confirm these findings.

One important caveat needs to be mentioned regarding the equal performance levels achieved through different administrations of lingual exercise, and that is that the only participant who did not receive lingual strengthening exercises in his "standard dysphagia therapy" protocol (Participant D) made similar improvements in overall swallowing function as the participants that did. Therefore, this study's findings could also indicate that lingual strengthening exercise may not be beneficial in patients with radiation/ chemoradiation-induced

dysphagia. Current dysphagia literature provides support for this interpretation as well. Specifically, Lazarus et al. (2014), found no benefit in groups in tongue strength, oropharyngeal swallow efficiency, or patient-reported quality of life for patients with radiation/ chemoradiation-induced dysphagia from lingual strengthening exercises administered via tongue depressor. As our findings could support this conclusion, more research needs to be done regarding the validity of using these exercises in patients with radiation/ chemoradiation-induced dysphagia.

This need for more research is also reflected in our findings for Participant A. This participant made no improvements in airway protection or pharyngeal retention over the course of this study, despite receiving both "standard dysphagia therapy" and a device-mediated lingual strengthening exercise protocol. While these results may be attributed to many factors, such as compliance, pain, or even depression, her results add interesting information to the dysphagia literature. Specifically, that treatment is not always effective for patients with radiation/ chemoradiation-induced dysphagia. However, another way one could view these results would be through the lens of her medical history. Specifically, over one year had elapsed between when she finished radiation/ chemoradiation, and when she began dysphagia treatment. Given the progressive nature of radiation/ chemoradiation-induced dysphagia symptoms, one could argue that a finding showing no improvement, but little regression is actually a positive result. Current research literature can neither support or refute this interpretation. Therefore, more work must be done to identify what constitutes an improvement in this patient population.

In summary, while our results did not provide robust evidence regarding the question we set out to answer, the data obtained opened doors to new questions and provided support to existing information in the research literature. Specifically, our data showed that tongue depressors might be as effective as more expensive device-mediated lingual strengthening

exercises protocols. We also demonstrated that there is a possibility that lingual strengthening exercise does not benefit this patient population, and that more research needs to be conducted to explore why. Last, our results also highlighted a paucity in the research literature regarding the definition of patient "improvement" in this patient population. Therefore, while our findings lend support, more research needs to be done.

4.2 RESEARCH QUESTION 2

What patient characteristics are shared by participants who showed improvement (benefits) from this form of dysphagia treatment?

The patient characteristic data obtained by this study revealed both commonalities and wide variation within the participants. Areas of commonality included gender and age. However, tumor location, staging, and time since radiation/ chemoradiation varied widely between participants. In regards to the participants who demonstrated improvements, observed common characteristics related to the timing of treatment, and primary lesion location. Interestingly, other characteristics, including tumor staging, participant age, and participant gender were not observed to be closely associated with either improvement or no improvement. These findings may contribute to a first-step towards guiding clinicians to create individualized dysphagia intervention plans.

4.2.1 Timing

Firstly, the data indicated that patients who had finished radiation/ chemoradiation over one-year before starting dysphagia treatment experienced less overall improvement than participants who began dysphagia treatment approximately two months after finishing radiation/ chemoradiation. Specifically, participants C, B, D, and F experienced higher levels of improvement, than participants A and E. Interestingly, participants C, B, D, and F also pursued dysphagia treatment approximately two months after completing radiation/ chemoradiation. In contrast, Participant A had over one year lapse between radiation/ chemoradiation and commencing dysphagia treatment, as did Participant E, who had more than seven years elapse. This observation is further supported because it is consistent with established findings in the dysphagia research literature (Lazarus et al., 2000). Therefore, the findings from this study combined with previously established findings (Lazarus et al., 2000) indicate that patients who have recently completed radiation/ chemoradiation may be the most appropriate for this type of intervention.

4.2.2 Location

Only three primary lesion locations were reported by participants in this study; the tonsils, the larynx, or the base of tongue. Lesion location information could not be obtained for one participant (Participant A). Participant E was the only participant who presented with a primary lesion in the larynx. While this participant experienced some improvement, there were no other participants who matched this characteristic. Therefore results could not be replicated through the multiple baselines aspect of this study, and no real observations can be made regarding this lesion location. The same goes for lesions on the base of tongue as Participant D was the only participant who

reported presenting with a primary lesion in this area. However, observations could be made regarding primary lesions in the tonsillar region as three participants reported primary lesions in this area.

Interestingly, the participant who demonstrated the greatest amount of swallowing improvement, and the participant that showed the second highest amount of swallowing improvement, both reported having had primary lesions in the tonsillar area. Specifically, Participant C showed the most considerable improvements in overall swallowing function as measured by airway protection and pharyngeal retention, in six of nine total opportunities (i.e. either airway protection and pharyngeal retention in all three swallow conditions). Participant B demonstrated the second greatest level of overall improvements, by improving in four of six total observations. These results indicate that exercise therapy may be beneficial for patients with lesions in the tonsillar region

However, it should be noted that Participant F also had a primary lesion in the tonsillar region, but he experienced a smaller proportion of improvement than participants B and C. More specifically, Participant F only showed improvements in airway protection and pharyngeal retention in three of the seven swallow conditions. However, it should be noted that the data set for this participant was incomplete. Therefore these results might not be representational, as it cannot be determined if this participant would have shown a more similar response to treatment overall if data could have been obtained for other observations.

4.2.3 Staging

In contrast to lesion location, tumor staging was not observed to coincide with participant results. For example, as previously discussed, Participant C and Participant B both had tonsillar cancers

and experienced similar rates of improvements. However, these two participants had remarkably different tumor staging. Specifically, Participant C was in the early stages (T2N2) while Participant B had more advanced staging (T4N2). This result indicates that this form of treatment may be appropriate for multiple stages of cancer. Interestingly, this result was further supported by the fact that tumor staging did not appear to influence results in the remainder of participants as no pattern could be detected. While the findings from this study were hardly conclusive, they may indicate that patients with a variety of tumor staging may benefit from this form of treatment.

4.2.4 Age and gender

Participant age ranges spanned approximately 21 years, as the youngest participant was 46 (Participant C), and the oldest was 67 (Participant A). Of note, the oldest participant showed the least amount of improvement, and the youngest participant showed the greatest. Therefore, age may be a very important factor in participant performance that needs to be tested with a larger sample under more controlled experimental conditions. Current research literature also supports this observation and the need for more research. Specifically, healthy people with advanced age present with differences in oropharyngeal movement patterns and temporospatial swallowing durations which may lead to the development of dysphagia (Gleeson, 1999; Logemann, 1990; Robbins, Levine, Wood, Roecker, & Luschei, 1995). While elderly patients with head and neck cancer may also present with these patterns, they are also at higher risk for associated complications due to primary cancer treatments such as polypharmacy and tissue toxicity (Maggiore et al., 2013; Maggiore et al., 2014). To date, it is unclear how much these co-occurring conditions contribute to patient outcomes as opposed to changes in swallowing associated with age, particularly since research has also demonstrated that some elderly patients with head and

neck cancer benefit from aggressive treatments (Maggiore et al., 2013). Therefore, while our results suggest that aging may adversely impact treatment outcomes, this is far from conclusive. More controlled research is needed to pinpoint whether aging is the causal factor, or whether these differences should be more accurately attributed to co-occurring conditions common in the aging population.

In regards to gender, only one participant identified as female (Participant A), whereas all of the other participants identified as male (Participants B, C, D, E, and F). As previously discussed, Participant A presented with the least amount of improvement in the study. Once again, while it is interesting that the only female participant did not benefit from this form of treatment, one participant's experience is hardly generalizable to females in general. Therefore, more research needs to be done examining the effects of gender on treatment outcomes for patients with radiation/ chemoradiation-induced dysphagia.

4.2.5 Summary

In summary, observations from this study data indicate that two patient characteristics may associate with greater improvements, specifically time since treatment and lesion location. Therefore, patients with these characteristics may be the most appropriate for this type of intervention. However, more research is needed to confirm this claim. As for the other participant characteristics examined, no observations could be made which coincided with participant performance. Therefore, more research is needed in this area to explore how different patients respond to dysphagia treatment.

4.3 STUDY STRENGTHS AND LIMITATIONS

This study featured both strengths and limitations. First, the major strength of this study was its high degree of external validity, by reflecting a "real-life" approach to standard dysphagia therapy. In clinical practice, clinician judgment forms the standard of care, and compensatory and rehabilitative techniques are prescribed for each patient based on their clinician's best judgment. Unfortunately, there is a large amount of variation both within and between clinicians in "real world" clinical practice. This variation was reflected in the uncontrolled nature of the standard dysphagia protocol used in this study. Therefore, the results obtained will be more reflective of what "real world" clinicians might expect, especially since the experimental protocol added to standard treatment within the study was very highly controlled. Because of this, the effects measured in this study can be confidently attributed to the addition of device-mediated isometric lingual strengthening exercises.

This study also featured major limitations. First, this study featured limited internal validity, due to the pre-post design, as the limited observations made it difficult to guarantee that results were caused by the experimental treatment and nothing else. While the multiple baselines across subjects feature of the design are supposed to guard against making this type of error, the heterogeneity of both participant and treatment-related factors limited effectiveness and prohibited accurate replication.

Vagueness in the device-mediated lingual strengthening exercise protocol may have also impacted the validity of results of this study, as the experimental protocol did not outline where exactly the IOPI bulb should be placed against the hard palate while completing the experimental exercise protocol. As different intrinsic muscles of the tongue account for various tongue movements, different bulb placements may target different intrinsic lingual muscles. Additionally,

there was no protocol in place to account for any bulb slippage which could occur during the implementation of exercises tasks. As slippage could also alter results, by creating deceptively small pressure measures, bulb slippage could also be a source of confounding.

Inconsistent adherence to the experimental protocols during data collection was another limitation of this study. Specifically, not all of the treating clinicians and radiologists followed the experimental protocols consistently while conducting the videofluoroscopic swallow study evaluations. As a result, the final data set was incomplete and contained limited observations per person. In fact, many participants had no observations in specific swallow conditions in either their "pre" or "post" studies, which severely limited the options for analysis. However, it is important to note that some of these alterations in the protocol were driven by observations of patient swallow function and clinical intervention priorities.

Clinicians also did not fully adhere to guidelines when prescribing exercises included in the "standard dysphagia therapy" protocol, for reasons unknown to the principal investigator (NB). Specifically, the original experimental protocol in the larger ongoing study defined "standard dysphagia therapy" as including any exercise other than those targeting lingual strength. However, after completion of the study it was discovered that two participants in the control group (Participant B and Participant F) were prescribed lingual strengthening exercises via tongue depressor as a part of their "standard dysphagia therapy" protocols. This inclusion of lingual strengthening exercise likely led to confounding, as the effects of lingual strengthening exercise can no longer be isolated since participants in both groups received some form of this type of exercise. Additionally, one participant in the experimental group, Participant E, was prescribed lingual strengthening exercises via tongue depressor as part of his "standard dysphagia therapy" protocol in addition to completing the device-mediated lingual strengthening exercise protocol.

This addition was problematic as both device-mediated and exercise administered via tongue depressor target the same thing, lingual strength. Therefore, as this participant completed more exercise than participants in the experimental group, it is impossible to attribute improvements he made in his swallowing to the device-mediated lingual strengthening protocol. In this way, inconsistent adherence to the experimental protocols regarding the prescription of lingual strengthening exercises within the "standard dysphagia therapy" protocols could have confounded the results of this study. Additionally, methodological considerations regarding clinician training in future studies should include the importance of adherence to scientific rigor by clinical staff during experimental research.

Last, videofluoroscopic films were recorded at a slower frame rate than what was originally planned by the principal investigators of the larger ongoing study (15 frames per second vs. 30 frames per second). As slower frame rates have been linked to less accurate observational analysis (Bonilha et al., 2013), measurement errors made due to a slower frame rate cannot be ruled out of this study. However, the magnitude of such errors would be no more than one-fifteenth of a second for any single durational measure and not likely to be systematic.

For future research, greater internal validity could be achieved with a more robust single-subject design such as alternating treatments or reversal/ withdrawal. If feasibility inhibited these options, then matching participants on all participant and situation variables could also decrease variability and improve internal validity. Additionally, future researchers could achieve more reliable results by using a faster frame rate and establishing formal documentation methods of medically necessary alterations of experimental protocol. In this way, necessary departures could be factored into statistical analysis. Last, future research could obtain more accurate results by establishing a formal training system to train prescribing clinicians in the exact nature of exercises

that should be included in the treatment protocols received by both the experimental and control groups.

5.0 CONCLUSION

Eating and drinking are fundamental aspects of the human experience, due to survival needs, comfort practices, cultural practices, and spiritual beliefs. A disruption in the ability to swallow therefore creates various adverse outcomes for patients, including negative personal health issues as well as psychosocial outcomes. This potential for negative consequences applies in particular for patients with radiation/ chemoradiation-induced dysphagia, due to the complexity of their underlying illness and the severity of swallowing disorders. Treating dysphagia in this patient population is one way that health care providers may work to improve patient outcomes in this particular patient population. However, the current research literature is not substantiated enough to guide intervention practices entirely.

5.1 SUMMARY

This study examined whether participants with radiation/ chemoradiation-induced dysphagia who completed device-mediated lingual strengthening exercises in addition to "standard dysphagia therapy" demonstrated greater improvements in airway protection and pharyngeal retention than those treated with "standard dysphagia therapy" alone. No consistent improvements were found to support the addition of device-mediated lingual strengthening exercise to "standard dysphagia therapy," possibly due to variations in the small sample size and flaws in methodology.

This study also examined some participant characteristics, in the hopes to inform future researchers and clinicians about which patients may benefit the most from this type of intervention.

Two observations were made regarding these characteristics. First, participants with the least amount of time-lapse between finishing radiation/ chemoradiation and commencing dysphagia treatment showed the greatest amount of overall improvement in both airway protection and pharyngeal retention. Second, participants with lesions in the tonsillar region also demonstrated higher levels of improvement following both "standard dysphagia therapy" and device-mediated lingual strengthening exercise in addition to "standard dysphagia therapy." These results indicate that patients with specific characteristics may stand to benefit from exercise treatment protocols. However, more research is needed to examine this claim.

5.2 SIGNIFICANCE

The dysphagia research literature does not currently have robust findings regarding how specific exercises impact swallowing function in patients with radiation/ chemoradiation-induced dysphagia. Nor does the research literature contain substantial information concerning participant characteristics and how they influence choosing one form of treatment over another. As dysphagia intervention must be individualized to the patient to be effective, these specific areas need to be explored further for clinicians to provide treatment in an effective and responsible manner. Therefore, this study is significant because it contributes information to two sparse areas of the research literature.

First, the findings are significant because they provide support to existing information in the research literature. Specifically, that tongue depressors might be equally effective to device-mediated lingual strengthening exercises protocols, and that lingual strengthening exercise may

not significantly benefit this patient population. However, more controlled research on a larger scale needs to be conducted to ascertain why. Additionally, our results highlighted a paucity in the research literature regarding the definition of patient "improvement" in this patient population. Therefore, out findings are significant because they lend support to these larger findings and highlight new questions for researchers to explore.

Additionally, this study identified two specific characteristics which may help researchers and clinicians identify patients who may benefit from this form of intervention, specifically participants with primary lesions in the tonsillar regions and who recently completed radiation/ chemoradiation treatments may be the most appropriate for this kind of intervention. Therefore, while this study does not lend robust evidence to the hypothesized research questions, our findings are still significant because they contribute information to lacking areas of the research literature.

APPENDIX A

METHODS OF THE LARGER ONGOING STUDY

Specific Aims

- To determine the effects of an eight-week device-mediated (IOPI) progressive lingual strengthening exercise program on lingual strength in patients with head and neck cancer.
- To determine the effects of an eight-week device-mediated (IOPI) progressive lingual strengthening exercise therapy program on:
    - Oral intake
    - Patient perception of impairment
    - Patient quality of life

Hypothesis When added to standard dysphagia therapy, device-mediated progressive resistive isometric lingual exercise will produce greater gains in lingual strength, oral intake, pharyngeal retention, and psychometric measures than standard therapy alone.

Dependent Variables The dependent variables included within this larger study are lingual strength, oral intake, Eat-10 questionnaire scores, and patient-reported severity of the disorder.

Design and Ethics The larger ongoing study is a prospective, experimental cohort study with a cross-over phase for patients in the control group, with the alternating assignment of participants to experimental and control groups. This study was approved by the Institutional Review Board of the University of Pittsburgh in November 2015 (PRO15080566). Written informed consent was obtained from all participants upon enrollment in the study.

Participants Participant recruitment occurs during evaluation in the Swallowing Disorders Center by the team physician and Speech Language Pathologist.

There are two inclusionary criteria. First, having been non-surgically treated with radiation or chemoradiation therapy for oral, oropharyngeal, hypopharyngeal, or laryngeal cancer and developed treatment associated dysphagia. Second, a minimum of one month was required to have transpired between the final radiation treatment and the initial study procedures, to ensure that acute effects of radiation/chemoradiation had subsided. There was no maximum post-treatment interval required for inclusion.

There are four exclusionary criteria. First, includes any cognitive deficits interfering with the participant's ability to adhere to assigned therapy program or ability to give informed consent. Second, a history of surgical treatment for head and neck cancer. Third, having a past or current history of temporomandibular joint dysfunction. Fourth, having a past or current history of myofascial pain disorders.

Consenting participants are alternately assigned to the two groups (experimental, control) based on the date of informed consent. The alternating assignment is used to avoid chronological bias and to maintain equal participant numbers within each group. Participants are assigned to either the control group (standard dysphagia treatment based on analysis of impairments) or experimental group (standard dysphagia treatment based on analysis of impairments plus device-mediated progressive resistive isometric lingual exercise using the IOPI device). Participants assigned to the control group are invited to cross over into the experimental protocol following completion of the eight-week dysphagia treatment phase. This study will conclude after 34 participants have completed protocols, 17 experimental and 17 control.

Dysphagia Assessment Phase Once eligibility was verified, and informed consent obtained, all participants underwent both instrumental and non-instrumental assessment measures. All assessments were completed by SLPs employed at UPMC including the primary researchers of the larger ongoing study. Research protocols were followed during each of these assessments, unless clinical needs superseded in the interest of participant safety.

Instrumental assessments consist of a Modified Barium Swallow Study (MBSS). All MBSS studies were performed on a Toshiba's Ultimax-i™ FPD system, set to 30 pulses per second. Recording utilized a Foresight Imaging TIMS Medical DICOM system (Foresight Imaging, 2016) at 15 frames per second.

Research protocol requires each participant to complete nine swallows, three in each of the three conditions. The first condition consists of command swallows of three-milliliter spoon thin liquid boluses in a neutral posture. The second condition consists of command swallows of three-milliliter spoon pudding thick boluses in a neutral posture. The third condition consisted of voluntary swallows of thin liquid boluses consumed freely from a cup in a neutral posture. All exams begin with the first condition. Upon completion of these conditions, additional swallows may be recorded, about individual treatment needs. However, these swallows are not standardized and not included in experimental data.

Following the initial VFS study, patient isometric lingual strength is measured via the IOPI device. The IOPI pressure sensor is placed against participants' hard palate, and clinicians give instructions to, "Push as hard as you can," for 30 seconds. Measurement is repeated five times. The average of the values of the five trials is then used to compute baseline lingual strength.

A Visual Analog Scale (VAS) is also administered to assess participants' perception of their swallowing problems (Boonstra, Schiphorst Preuper, Reneman, Posthumus, & Stewart,

2008). This scale consists of a 100 mm line numbered from 0-100. Participants are instructed to mark an "X" that is representative of their perceived problems with "0" representing no problems and "100" extremely severe problems.

The EAT-10 dietary questionnaire is also administered by clinicians as a standardized tool to describe both patient quality of life and feeding status (Cheney et al., 2015). The Function Oral Intake Scale (FOIS) is completed by the treating clinician to rate the participants' current levels of oral intake (Crary, Mann, & Groher, 2005). Last, participants are weighed by their treating clinician to track adequacy of nutritional intake.

Treating clinicians prescribe all participants "standard dysphagia therapy" interventions, consisting of interventions other than lingual strengthening exercises, and train participants in these interventions. Decisions regarding the prescription of dysphagia interventions are made by the SLP based entirely on clinical factors including participant impairments and clinician judgment. This training includes compensatory swallow maneuvers, range of motion exercises, as well as dietary and texture modifications.

Experimental participants additionally receive 30-minutes of training in the operation of the IOPI device and performance of the experimental exercise protocol. Daily exercise logs are dispensed for participants to record all therapy activities performed outside of the clinic.

Dysphagia Treatment Phase Dysphagia treatment commences immediately following assessment procedures, consisting of an eight-week therapy regimen.

Participants assigned to the control group complete their individually prescribed "standard dysphagia therapy" interventions throughout this eight-week period. All dysphagia treatments other than isometric lingual exercises are considered for participants in this group, as isometric

exercise has not currently been proven beneficial. After the eighth week of dysphagia treatment, participants in the control group are invited to cross over into the experimental protocol, continuing with standard intervention with the addition of IOPI mediated resistive isometric exercises.

Participants assigned to the experimental group complete their individually prescribed "standard dysphagia therapy" interventions throughout this eight-week period. In addition to the "standard dysphagia therapy," participants within the experimental group also complete device-mediated progressive resistive isometric exercises. Participants perform three sets of ten repetitions of isometric lingual "presses" daily for three nonconsecutive days per week, compressing the IOPI sensor between the tongue and hard palate for three seconds per repetition. Exercise targets for this protocol are based on assessment strength measures, which are calculated based on the methods of Robbins et al. (2005). Based on these methods, 60% of maximal isometric strength is the exercise target for the first week of treatment, increasing to 80% for weeks two through eight. At the beginning of weeks three, five, and seven, strength was re-measured and the 80% target recalculated. Exercise logs are used to enhance compliance. For all participants, UPMC clinicians re-administer all measures completed during the assessment phase at the end of the eighth week of the research procedures to determine outcomes measures.

Cross-Over Phase Participants in the control group who choose to cross over into the experimental protocol continue with their prescribed "standard dysphagia therapy" interventions with the addition of IOPI mediated resistive isometric exercises. These participants undergo all assessment measures again at the end of week 16.

BIBLIOGRAPHY

Adams, V., Mathisen, B., Baines, S., Lazarus, C. L., & Callister, R. (2013). A Systematic Review and Meta-analysis of Measurements of Tongue and Hand Strength and Endurance Using the Iowa Oral Performance Instrument (IOPI). *Dysphagia, 28:350–369.* doi:DOI 10.1007/s00455-013-9451-3

American College of Sports Medicine. (1998). American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Medicine and Science in Sports Exercise, 30*(6), 975-991.

Bonilha, H. S., Blair, J., Carnes, B., Huda, W., Humphries, K., McGrattan, K., . . . Martin-Harris, B. (2013). Preliminary investigation of the effect of pulse rate on judgments of swallowing impairment and treatment recommendations. *Dysphagia, 28*(4), 528-538. doi:10.1007/s00455-013-9463-z

Boonstra, A. M., Schiphorst Preuper, H. R., Reneman, M. F., Posthumus, J. B., & Stewart, R. E. (2008). Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. *International Journal of Rehabilitation Research, 31*(2), 165-169. doi:10.1097/MRR.0b013e3282fc0f93

Boscolo-Rizzo, P., Maronato, F., Marchiori, C., Gava, A., & Da Mosto, M. C. (2008). Long-term quality of life after total laryngectomy and postoperative radiotherapy versus concurrent chemoradiotherapy for laryngeal preservation. *Laryngoscope, 118*(2), 300-306. doi:10.1097/MLG.0b013e31815a9ed3

Brierley, J. (2006). The evolving TNM cancer staging system: an essential component of cancer care. *CMAJ : Canadian Medical Association Journal, 174*(2), 155-156. doi:10.1503/cmaj.045113

Cabib, C., Ortega, O., Kumru, H., Palomeras, E., Vilardell, N., Alvarez-Berdugo, D., . . . Clave, P. (2016). Neurorehabilitation strategies for poststroke oropharyngeal dysphagia: from compensation to the recovery of swallowing function. *Annals of the New York Academy of Science*. doi:10.1111/nyas.13135

Callaway, C. (2011). Rethinking the head and neck cancer population: the human papillomavirus association. *Clinical Journal of Oncology Nursing, 15*(2), 165-170. doi:10.1188/11.cjon.165-170

Carnaby-Mann, G., Crary, M. A., Schmalfuss, I., & Amdur, R. (2012). "Pharyngocise": randomized controlled trial of preventative exercises to maintain muscle structure and swallowing function during head-and-neck chemoradiotherapy. *International Journal of Radiation Oncology, Biology, Physics, 83*(1), 210-219. doi:10.1016j.ijrobp.2011.06.1954

Cheney, D. M., Siddiqui, M. T., Litts, J. K., Kuhn, M. A., & Belafsky, P. C. (2015). The Ability of the 10-Item Eating Assessment Tool (EAT-10) to Predict Aspiration Risk in Persons With Dysphagia. *Annals of Otology, Rhinology,and Laryngology, 124*(5), 351-354. doi:10.1177/0003489414558107

Christiaanse, M. E., Mabe, B., Russell, G., Simeone, T. L., Fortunato, J., & Rubin, B. (2011). Neuromuscular electrical stimulation is no more effective than usual care for the treatment of primary dysphagia in children. *Pediatric Pulmonology, 46*(6), 559-565. doi:10.1002/ppul.21400

Cicchetti, D. V. (1994). Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instrument in Psychology. *Psychological Assessment, 6*(4), 284-290. doi:10.1037/1040-3590.6.4.284

Cooper, R. A., Quatrano, L. A., Axelson, P. W., Harlan, W., Stineman, M., Franklin, B.,...Painter, P. (1999). Research on physical activity and health among people with disabilities: a consensus statement. *J Rehabilitation Research and Development, 36*(2), 142-154.

Coyle, J. L. (2012). Biomechanical anaylsis *Videofluoroscopy: a multidisciplinary approach* (pp. 107-121). San Diego: Plural Publishing.

Crary, M. A., Mann, G. D., & Groher, M. E. (2005). Initial psychometric assessment of a functional oral intake scale for dysphagia in stroke patients. *Archives of Physical Medicine and Rehabilitation, 86*(8), 1516-1520. doi:10.1016/j.apmr.2004.11.049

Delanian, S., Lefaix, J. L., & Pradat, P. F. (2012). Radiation-induced neuropathy in cancer survivors. *Radiotherapy and Oncology, 105*(3), 273-282. doi:10.1016/j.radonc.2012.10.012

Eisenhuber, E., Schima, W., Schober, E., Pokieser, P., Stadler, A., Scharitzer, M., & Oschatz, E. (2002). Videofluoroscopic assessment of patients with dysphagia: pharyngeal retention is a predictive factor for aspiration. *American Journal of Roentgenology, 178*(2), 393-398. doi:10.2214/ajr.178.2.1780393

Foresight Imaging. (2016). TIMS DICOM System. Chelmsford, MA: Foresight Imaging.

Fujiu, M., & Logemann, J. A. (1996). Effect of a Tongue-Holding Maneuver on Posterior Pharyngeal Wall Movement During Deglutition. *American Journal of Speech-Language Pathology, 5*(1), 23-30. doi:10.1044/1058-0360.0501.23

Fuller, S. C., Leonard, R., Aminpour, S., & Belafsky, P. C. (2009). Validation of the pharyngeal squeeze maneuver. *Otolaryngology: Head and Neck Surgery, 140*(3), 391-394. doi:10.1016/j.otohns.2008.12.015

Funk, G. F., Karnell, L. H., Christensen, A. J., Moran, P. J., & Ricks, J. (2003). Comprehensive head and neck oncology health status assessment. *Head and Neck, 25*(7), 561-575. doi:10.1002/hed.10245

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., . . . Swain, D. P. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports Exercise*, *43*(7), 1334-1359.

Gleeson, D. C. L. (1999). Oropharyngeal swallowing and aging: A review. *Journal of Communication Disorders*, *32*(6), 373-396. doi:http://dx.doi.org/10.1016/S0021-9924(99)00017-9

Goh, H. K., Ng, Y. H., & Teo, D. T. (2010). Minimally invasive surgery for head and neck cancer. *Lancet Oncology*, *11*(3), 281-286. doi:10.1016/s1470-2045(09)70379-1

Hutcheson, K. A., Bhayani, M. K., Beadle, B. M., Gold, K. A., Shinn, E. H., Lai, S. Y., & Lewin, J. (2013). Eat and exercise during radiotherapy or chemoradiotherapy for pharyngeal cancers: use it or lose it. *JAMA Otolaryngology Head and Neck Surgery*, *139*(11), 1127-1134. doi:10.1001/jamaoto.2013.4715

IOPI Medical. (2013). Invention History. Retrieved from http://iopimedical.com/medical-professionals/

Jamal, N., Erman, A., & Chhetri, D. K. (2015). Partial Epiglottoplasty for Pharyngeal Dysphagia due to Cervical Spine Pathology. *Otolaryngology Head and Neck Surgery*, *153*(4), 586-592. doi:10.1177/0194599815601025

Kays, S., & Robbins, J. (2006). Effects of sensorimotor exercise on swallowing outcomes relative to age and age-related disease. *Seminars in Speech and Language*, *27*(4), 245-259. doi:10.1055/s-2006-955115

Kenny, B. (2015). Food Culture, Preferences and Ethics in Dysphagia Management. *Bioethics*, *29*(9), 646-652. doi:10.1111/bioe.12189

Kim, G. E., Lee, S. W., Chang, S. K., Park, H. C., Pyo, H. R., Kim, J. H., . . . Kim, K. M. (2001). Combined chemotherapy and radiation versus radiation alone in the management of localized angiocentric lymphoma of the head and neck. *Radiotherapy and Oncology*, *61*(3), 261-269.

Kraaijenga, S. A., Oskam, I. M., van der Molen, L., Hamming-Vrieze, O., Hilgers, F. J., & van den Brekel, M. W. (2015). Evaluation of long term (10-years+) dysphagia and trismus in patients treated with concurrent chemo-radiotherapy for advanced head and neck cancer. *Oral Oncology*, *51*(8), 787-794. doi:10.1016/j.oraloncology.2015.05.003

Krauskopf, K. A., Beiser, A., & Carey, C. D. (1997). *The Physical Universe* (8th ed.). New York City: McGraw-Hill.

Krisciunas, G. P., Sokoloff, W., Stepas, K., & Langmore, S. E. (2012). Survey of usual practice: dysphagia therapy in head and neck cancer patients. *Dysphagia, 27*(4), 538-549. doi:10.1007/s00455-012-9404-2

Langmore, S. E., Terpenning, M. S., Schork, A., Chen, Y., Murray, J. T., Lopatin, D., & Loesche, W. J. (1998). Predictors of aspiration pneumonia: how important is dysphagia? *Dysphagia, 13*(2), 69-81. doi:10.1007/pl00009559

Lazarus, Logemann, J. A., Huang, C. F., & Rademaker, A. W. (2003). Effects of two types of tongue strengthening exercises in young normals. *Folia Phoniatrica et Logopaedia, 55*(4), 199-205. doi:71019

Lazarus, C., Logemann, J. A., Huang, C. F., & Rademaker, A. W. (2003). Effects of two types of tongue strengthening exercises in young normals. *Folia Phoniatrica et Logopaedia, 55*(4), 199-205. doi:71019

Lazarus, C. L., Husaini, H., Falciglia, D., DeLacure, M., Branski, R. C., Kraus, D., . . . Sanfilippo, N. (2014). Effects of exercise on swallowing and tongue strength in patients with oral and oropharyngeal cancer treated with primary radiotherapy with or without chemotherapy. *International Journal of Oral Maxillofacial Surgery, 43*(5), 523-530. doi:10.1016/j.ijom.2013.10.023

Lazarus, C. L., Logemann, J. A., Pauloski, B. R., Colangelo, L. A., Kahrilas, P. J., Mittal, B. B., & Pierce, M. (1996). Swallowing disorders in head and neck cancer patients treated with radiotherapy and adjuvant chemotherapy. *Laryngoscope, 106*(9 Pt 1), 1157-1166.

Lazarus, C. L., Logemann, J. A., Pauloski, B. R., Rademaker, A. W., Larson, C. R., Mittal, B. B., & Pierce, M. (2000). Swallowing and tongue function following treatment for oral and oropharyngeal cancer. *Journal of Speech Language Hearing Research, 43*(4), 1011-1023.

Lee, C. C., Lin, Y. S., Kang, B. H., Chang, K. P., Chi, C. C., Lin, M. Y., . . . Yang, C. C. (2016). Incorporation of log odds of positive lymph nodes into the AJCC TNM classification improves prediction of survival in oral cancer. *Clinical Otolaryngology*, 42 (2), 425-432.

Lof, G. L., & Robbins, J. (1990). Test-retest Variability in Normal Swallowing. *Dysphagia, 4*, 236-242.

Logemann, J. A. (1990). Effects of aging on the swallowing mechanism. *Otolaryngologic Clinics of North America, 23*(6), 1045-1056.

Logemann, J. A., Kahrilas, P. J., Begelman, J., Dodds, W. J., & Pauloski, B. R. (1989). Interactive computer program for biomechanical analysis of videoradiographic studies of swallowing. *American Journal of Roentgenology, 153*(2), 277-280. doi:10.2214/ajr.153.2.277

Logemann, J. A., Pauloski, B. R., Rademaker, A. W., Lazarus, C. L., Gaziano, J., Stachowiak, L., . . . Mittal, B. (2008). Swallowing disorders in the first year after radiation and chemoradiation. *Head and Neck, 30*(2), 148-158. doi:10.1002/hed.20672

Maggiore, R. J. (2016). Locally advanced head and neck cancer in either the older or the vulnerable adult: Making the case for a team-based, "gero-centric" approach. *Journal of Geriatric Oncology, 7*(5), 334-340. doi:10.1016/j.jgo.2016.06.004

Maggiore, R. J., Curran, E. K., Witt, M. E., Haraf, D. J., Vokes, E. E., & Cohen, E. E. (2013). Survival and selected outcomes of older adults with locally advanced head/neck cancer treated with chemoradiation therapy. *Journal of Geriatric Oncology, 4*(4), 327-333. doi:10.1016/j.jgo.2013.05.003

Maggiore, R. J., Dale, W., Gross, C. P., Feng, T., Tew, W. P., Mohile, S. G., . . . Hurria, A. (2014). Polypharmacy and potentially inappropriate medication use in older adults with cancer undergoing chemotherapy: effect on chemotherapy-related toxicity and hospitalization during treatment. *Journal of the American Geriatric Society, 62*(8), 1505-1512. doi:10.1111/jgs.12942

Marieb, E. N., Hoen, K. (2011). *Anatomy and Physiology* (Fourth ed.). New York City: Pearson.

Marik , P. E. (2001). Aspiration Pneumonitis and Aspiration Pneumonia. *New England Journal of Medicine, 344*(9), 665-671. doi:10.1056/NEJM200103013440908

Martino, R., Silver, F., Teasell, R., Bayley, M., Nicholson, G., Streiner, D. L., & Diamant, N. E. (2009). The Toronto Bedside Swallowing Screening Test (TOR-BSST): development and validation of a dysphagia screening tool for patients with stroke. *Stroke, 40*(2), 555-561. doi:10.1161/STROKEAHA.107.510370

Matsuo, K., & Palmer, J. B. (2008). Anatomy and physiology of feeding and swallowing: normal and abnormal. *Physical Medicine and Rehabilitation Clinics of North America, 19*(4), 691-707, vii. doi:10.1016/j.pmr.2008.06.001

McLaughlin, L. (2013). Taste dysfunction in head and neck cancer survivors. *Oncology Nursing Forum, 40*(1), E4-13. doi:10.1188/13.ONF.E4-E13

Mikaeli, J., Farrokhi, F., Bishehsari, F., Mahdavinia, M., & Malekzadeh, R. (2006). Gender effect on clinical features of achalasia: a prospective study. *BMC Gastroenterology, 6*, 12. doi:10.1186/1471-230x-6-12

National Cancer Institute. (2016a). Head and Neck Cancer - Health Professional Version. Retrieved from https://www.cancer.gov/types/head-and-neck/hp/hypopharyngeal-treatment-pdq

National Cancer Institute. (2016b). Radiation Therapy for Cancer. *Cancer Treatment.* Retrieved from http://www.cancer.gov/about-cancer/treatment/types/radiation-therapy/radiation-fact-sheet

National Cancer Institute. (2017). Cancer Stat Facts: Oral Cavity and Pharynx Cancer. *Surveillance, Epidemiology, and End Results Program.* Retrieved from https://seer.cancer.gov/statfacts/html/oralcav.html

Nicosia, M. A., & Robbins, J. A. (2001). The fluid mechanics of bolus ejection from the oral cavity. *Journal of Biomechanics, 34*(12), 1537-1544.

Nund, R. L., Ward, E. C., Scarinci, N. A., Cartmill, B., Kuipers, P., & Porceddu, S. V. (2014). Survivors' experiences of dysphagia-related services following head and neck cancer: implications for clinical practice. *International Journal of Language Communication Disorders, 49*(3), 354-363. doi:10.1111/1460-6984.12071

Palm, A., & Johansson, K. A. (2007). A review of the impact of photon and proton external beam radiotherapy treatment modalities on the dose distribution in field and out-of-field; implications for the long-term morbidity of cancer survivors. *Acta Oncologica, 46*(4), 462-473. doi:10.1080/02841860701218626

Rademaker, A. W., Pauloski, B. R., Logemann, J. A., & Shanahan, T. K. (1994). Oropharyngeal swallow efficiency as a representative measure of swallowing function. *Journal of Speech and Hearing Research, 37*(2), 314-325.

Rashband, T., & Ferreria, W. (2016). Image J (Version 1.5g): Image J.

Robbins, J., Gangnon, R. E., Theis, S. M., Kays, S. A., Hewitt, A. L., & Hind, J. A. (2005). The effects of lingual exercise on swallowing in older adults. *J Am Geriatr Soc, 53*(9), 1483-1489. doi:10.1111/j.1532-5415.2005.53467.x

Robbins, J., Kays, S. A., Gangnon, R. E., Hind, J. A., Hewitt, A. L., Gentry, L. R., & Taylor, A. J. (2007). The effects of lingual exercise in stroke patients with dysphagia. *Archives of Physical Medicine Rehabilitation, 88*(2), 150-158. doi:10.1016/j.apmr.2006.11.002

Robbins, J., Levine, R., Wood, J., Roecker, E. B., & Luschei, E. (1995). Age effects on lingual pressure generation as a risk factor for dysphagia. *Journals of Gerontology, Series A, Biological Sciences and Medical Sciences, 50*(5), M257-262.

Rogers, S. N., D'Souza, J. J., Lowe, D., & Kanatas, A. (2015). Longitudinal evaluation of health-related quality of life after osteoradionecrosis of the mandible. *British Journal of Oral Maxillofacial Surgery, 53*(9), 854-857. doi:10.1016/j.bjoms.2015.07.008

Rogus-Pulia, N., Rusche, N., Hind, J. A., Zielinski, J., Gangnon, R., Safdar, N., & Robbins, J. (2016). Effects of Device-Facilitated Isometric Progressive Resistance Oropharyngeal

Therapy on Swallowing and Health-Related Outcomes in Older Adults with Dysphagia. *Journal of the American Geriatric Society*. doi:10.1111/jgs.13933

Rosenbek, J. C., Robbins, J. A., Roecker, E. B., Coyle, J. L., & Wood, J. L. (1996). A penetration-aspiration scale. *Dysphagia, 11*(2), 93-98.

Shaker, R., Easterling, C., Kern, M., Nitschke, T., Massey, B., Daniels, S., . . . Dikeman, K. (2002). Rehabilitation of swallowing by exercise in tube-fed patients with pharyngeal dysphagia secondary to abnormal UES opening. *Gastroenterology, 122*(5), 1314-1321.

Shapiro, B. E., Rordorf, G., Schwamm, L., & Preston, D. C. (1996). Delayed radiation-induced bulbar palsy. *Neurology, 46*(6), 1604-1606.

Smith, B. S., Adams, Mikael. (2012). *Otolaryngology Research Advances: Dysphagia: Risk Factors, Diagnosis and Treatment : Risk Factors, Diagnosis and Treatment* (9781619421042, Trans.). Hauppauge: Nova.

Steel, G. G., & Peckham, M. J. (1979). Exploitable mechanisms in combined radiotherapy-chemotherapy: the concept of additivity. *Inter J Radiation Oncology, Bio, Phy, 5*(1), 85-91.

Suiter, D. M., Sloggy, J., & Leder, S. B. (2014). Validation of the Yale Swallow Protocol: a prospective double-blinded videofluoroscopic study. *Dysphagia, 29*(2), 199-203. doi:10.1007/s00455-013-9488-3

Wada, S., Tohara, H., Iida, T., Inoue, M., Sato, M., & Ueda, K. (2012). Jaw-opening exercise for insufficient opening of upper esophageal sphincter. *Archives of Physical Medicine and Rehabilitation, 93*(11), 1995-1999. doi:10.1016/j.apmr.2012.04.025

Ward, E. C., Morgan, Angela T. . (2009). *Dysphagia Post Trauma*. San Diego: Plural Publishing.

Yusuf, S. W., Sami, S., & Daher, I. N. (2011). Radiation-induced heart disease: a clinical update. *Cardiology Research and Practice, 2011*, 317659. doi:10.4061/2011/317659