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VIDEOFLUOROSCOPIC ANALYSIS TO DETERMINE THE EFFECTS OF THICKENED LIQUIDS ON OROPHARYNGEAL SWALLOWING FUNCTION IN INFANTS WITH RESPIRATORY COMPROMISE

by

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Dedication

This dissertation is dedicated to my husband, Joe, and my children, Tucker and Sam, in recognition of their support throughout this educational process. They have been a source of inspiration and encouragement. I am grateful for my family and I know that I would never have been able to finish this project without them.

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I wish to thank my family for supporting me throughout my educational experiences. My parents, Bill and Sharon Mintz, have always emphasized the importance of education and I know that this would not have been possible without their support at each step in this journey. My husband, Joe, has been a source of strength and encouragement during this experience. I know he thought I was crazy for going back to school; I appreciate his support despite his questioning of my sanity. My children, Tucker and Sam, were the inspiration for returning to school and I appreciate their understanding and patience along the way.

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Abstract

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In clinical practice, infants who present with dysphagia during instrumental assessment are frequently placed on a diet that includes thickened liquids. There is scant empirical evidence available to support this common treatment practice. Studies that have previously attempted to evaluate the effectiveness of thickened liquids as a treatment option for infants with dysphagia have been limited by poorly defined physiologic parameters and small, heterogeneous populations of study. The purpose of this dissertation was to systematically evaluate the effects of thickened liquids in a homogenous sample of infants through retrospective analysis of archived videofluoroscopic swallow studies. Fifteen different temporal and physiologic measures were recorded from frame by frame analysis of 242 swallows selected from the videofluoroscopic swallowing studies of 25 infants with respiratory compromise. Each subject provided a sample of both thin and nectar thickened liquid swallows for comparison. In total, 121 swallows of thin liquid barium and 121 swallows of nectar thickened liquid barium were analyzed. Significant differences were found among the following variables between swallows of thin liquid barium and swallows of nectar thickened liquid barium: number of sucks per swallow, suck time, oral transit time, time to initiate velar movement, scores on the penetration-aspiration scale, location of the bolus before the swallow, and presence of residue after the swallow. There were greater numbers of sucks per swallow, longer suck and oral transit times, lower mean scores on the penetration-aspiration scale, and longer time to initiate velar movement for swallows of nectar thickened liquid barium as compared to swallows of thin liquid barium. Bolus material collected at a more inferior location along the upper aerodigestive tract during swallows of the nectar thickened liquid barium. There was greater frequency of residue in the pharynx following swallows of the nectar thickened liquid barium. The contribution of these variables to overall swallowing safety is discussed. Results point to improved swallowing safety with the use of nectar thickened liquids as a result of prolonging the oral phase of swallowing, thereby reducing the frequency of pharyngeal swallow and opportunities for airway compromise during bottle feeding.

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Chapter 1: Introduction

The prevalence of dysphagia among infants and children has been estimated as high as 80% in those classified as developmentally delayed (Arvedson, 2008; Lefton-Greif & Arvedson, 2007). The high prevalence of dysphagia among the pediatric population may in part be explained by the improved survival rates of infants born with a variety of medical conditions such as prematurity, low birth weight, complex, medical conditions, cerebral palsy, and developmental delay (not otherwise specified) (Arvedson, 2008; Lefton-Greif, 2008; Newman, Keckley, Petersen, & Hamner, 2001). Lefton Greif (2008) proposes that the causes of pediatric dysphagia may arise from five broad diagnostic categories: 1) neurologic disorders, 2) anatomic abnormalities of the aerodigestive tract, 3) genetic conditions including syndromes and craniofacial anomalies, 4) conditions affecting suck-swallowing-breathing rhythmicity including congenital malformations of the aerodigestive tract (such as laryngomalacia and choanal atresia), and 5) acquired conditions (such as bronchopulmonary dysplasia and respiratory syncytial virus) and other correlated conditions such as gastroesophageal reflux disease (GERD) and pervasive developmental delay (PDD).

Clinical manifestations of dysphagia in the pediatric population may include one or more of the following: recurrent episodes of aspiration, multiple episodes of respiratory infection, and the possibility of developing chronic lung disease (Tuchman, 1988). Aspiration lung disease is a general term that can refer to a range of clinical presentations, from a single massive event of aspiration to ongoing lung aspiration, as can be common in infants with dysphagia. Aspiration lung disease has the potential to cause permanent damage to the developing lungs of infants and children. Pulmonary aspiration (a component of aspiration lung disease) is most commonly the result of dysphagia (swallowing dysfunction), gastroesopheageal reflux disease (GERD), or insufficient management of oral secretions (de Benedictis, Carnielli, & de Benedictis, 2009). Effective diagnosis and management of pediatric dysphagia is essential to minimizing the detrimental and potentially lethal effects of uncontrolled aspiration (de Benedictis et al., 2009; Newman, 2000). Development of any of the previously mentioned sequelae may result in poor oral intake and subsequent protein energy malnutrition (PEM). PEM may then result in impairment to the immunologic response to subsequent infections that negatively impact the development of the central nervous system in the infant (Tuchman, 1988). In general, dysphagia in the pediatric population has a direct impact on caloric intake and overall nutritional status affecting maturation of all of the developing body systems in infants and children (Newman, 2000).

Despite the high prevalence and negative outcomes associated with dysphagia in this vulnerable population, there are very few documented effective treatment strategies. Typical dysphagia treatment strategies are divided into direct and indirect categories. Direct strategies involve maneuvers or exercises that the patient must participate in to improve swallowing function. Indirect strategies involve manipulation of the food substances or environment to help facilitate safe swallowing. Due to limited cognitive and physical capabilities, indirect strategies are most commonly employed for the pediatric patient. Among the indirect strategies available, increasing the viscosity of liquids-more commonly known as “thickening liquids” is one of the most frequently used strategies. In a recent evidence based systematic review, Gosa, Schooling, and Coleman (2011) examined the available evidence for using thickened liquids in pediatric populations. The authors reported on six papers that met their inclusion criteria and addressed the question pertaining to the efficacy of thickened liquid use in the pediatric population. The majority of the patients included in these six papers were under the age of one year. Each of the six papers reported some level of improvement in swallowing function with the use of thickened liquids; however, they failed to identify the physiologic mechanism behind the reported improvement. The review article also highlights the lack of consistency among thickening agents, patient populations, and methods used in the very few published papers reporting on the use of thickened liquids in pediatric patients.

Infants and children with dysphagia represent a heterogenous group of patients. Dysphagia is a secondary diagnosis and typically stems from a primary cause that effect the central nervous system, the respiratory system, or the gastrointestinal system. Pediatric patients with dysphagia must be carefully screened into diagnostic categories to better understand the underlying physiologic mechanisms that create airway compromise and risk for malnutrition in this population. The current literature falls short of this feature of scientific rigor and instead relies on general description of dysphagia symptoms (laryngeal penetration, aspiration, or nasopharyngeal backflow) without defining the causal relationship. As a result, the findings from the available literature are not easily translated into clinical practice. An additional challenge to studying this population is the developmental nature of feeding. Infants do not represent miniature versions of adult anatomy and physiology. Instead, they represent unique beings at each stage along the feeding and anatomical developmental continuum. Treatment strategies that were found to be effective in the adult populations do not always translate seamlessly to pediatric populations due to the differences in underlying anatomy and maturation of the individual body systems.

The purpose of this dissertation was to determine the physiologic effects of providing thickened liquids as a treatment option to a homogeneous population of infants that present with dysphagia. Specifically the study focused on infants between one week and three months of age that had a primary respiratory diagnosis and were referred for dysphagia evaluation utilizing modified barium swallow study. To investigate what, if any effect, thickened liquids had on the oropharyngeal swallow function in this population, the researcher utilized frame-by-frame analysis of previously recorded modified barium swallow studies that included swallows of both thin and nectar thickened liquid barium from a standard, one-hole nipple. This type of research has broad clinical applications and will lay the foundation for further investigation of dysphagia in diagnosis and developmentally specific pediatric populations.

Chapter 2: Background

Respiration

There are immediate, life sustaining demands placed on newborns. As soon as they emerge from the aquatic intrauterine environment, the infant becomes responsible for oxygenating the body through respiration. Respiration refers to the physiologic process of transporting oxygen from the environment into the body and moving carbon dioxide out of the body. Without an adequate means for accomplishing respiration, the infant will not survive. The respiratory system in term infants is primed and activated during the birthing process (Smith, 1959).

The respiratory system can be thought of as two distinct tracts. The upper airway includes the nose, pharynx, and larynx. The lower airway is composed of the trachea, bronchi, bronchioles, alveolar ducts, alveoli, and pleura. The upper airway is the conduit for the gaseous exchange of oxygen into the body and carbon dioxide out of the body. The lower airway lays the path for oxygen to enter the alveoli of the lungs. The exchange of gases in the body occurs at the end of the airway in the alveolar sacs. The alveolar sacs are surrounded by millions of capillaries which allows for diffusion of oxygen from inhalation across the alveolocapillary membrane and diffusion of carbon dioxide from the blood back into the lungs to be released into the environment during exhalation (Ball, Bindler, & Cowen, 2010).

The lungs are positioned in the thoracic cavity. In the thoracic cavity, the lungs rely on the ribs and diaphragm for biomechanical support and protection. The intercostal muscles work with the diaphragm to lower the pressure in the thoracic cavity, which in turn increases the volume in the thoracic cavity. The lower pressure and increased volume of the thoracic cavity pulls air into the lungs during inspiration. The lungs and chest expand during inspiration and then recoil to their resting state during expiration (Ball et al., 2010). Those infants born following an uncomplicated, 40 week gestation typically participate in the work of breathing without excessive effort. In cases of infants born prematurely or those born with disorders that decrease the compliance of the lungs or obstruct the airways, there can be increased muscular effort and poor oxygenation despite maximal effort.

Respiration is driven by the bodies need to supply oxygen for necessary metabolic functions and to remove carbon dioxide from the body to prevent toxicity. This is mostly an involuntary process with the respiratory center of the central nervous system being housed in the medulla oblongata. The respiratory center responds to neural, chemical, and hormonal signals to regulate breathing by adjusting the rate and depth of inhalation and exhalation. In healthy individuals, it is usually the elevated presence of carbon dioxide detected by chemoreceptors in the blood that signals the respiratory center to breathe (Bhatnagar, 2008). In healthy infants, a respiratory rate of 30-60 breaths per minute is optimal (Ball et al., 2010).

Infants are especially vulnerable to conditions that affect their respiratory competency due to their physical and neurologic immaturity. Conditions that affect the patency of the upper or lower airways or those conditions that impair oxygenation of the blood at the level of the alveoli can cause rapid overall decline in the infant’s health. The progression from difficulty breathing to respiratory distress to respiratory failure can be sudden and often quite rapid in newborns. Common causes of respiratory distress in infants include the following: laryngotracheobronchitis (croup), epiglottitis, neonatal respiratory distress syndrome, meconium aspiration syndrome, respiratory distress syndrome, transient tachypnea of the newborn, bronchitis, bronchiolitis, respiratory syncytial virus, pneumonia, bronchopulmonary dysplasia, wheezing, and cystic fibrosis. Each of these conditions has a unique etiology, pathophysiology, and plan of care; however, they share the common symptom of increasing metabolic and respiratory demands on the infant. They all result in increased respiratory effort and typically cause an elevated basal respiratory rate (Ball et al., 2010). As a consequence of respiratory impairment, other life sustaining functions are negatively impacted- namely feeding.

Stages of Feeding and Swallowing

Shortly after birth, newborns will begin to suckle from either their mother’s breast or from a bottle to gain the nutrients necessary to grow and thrive in the extrauterine environment. While breastfeeding is the preferred method of feeding for all infants, it is not always a practical option (Bakwin, 1953). Many infants that are born prematurely or with other life threatening conditions cannot immediately take any nutrition by mouth at birth. Infants with complicated health issues are frequently bottle fed once their health status has stabilized. The physiologic process of bottle-feeding can be understood by examining it in light of the four stages of swallowing.

Swallowing is typically described in the following four stages: oral preparatory, oral transit, pharyngeal, and esophageal. In the oral preparatory phase, there is sensory recognition of the liquid or food source prior to it entering the oral cavity. Successful oral preparation depends on good oral seal, patent nasal airway, lingual manipulation to hold the bolus in the oral cavity, and bolus lateralization for mastication if necessary. If mastication is not necessary, the soft palate will assume a downward and forward position to seal the oral cavity from the pharynx. The larynx and pharynx are not active during the oral preparatory phase of swallowing and the airway is open allowing respiration during this phase of swallowing. Once the bolus is prepared it is positioned on the lingual midblade. The oral preparatory stage varies in length depending on the type of bolus to be swallowed (Logemann, 1998).

The oral transit phase of swallowing begins with posterior movement of the tongue. This action propels the bolus posteriorly in the oral cavity towards the pharynx. Typically, the midblade of the tongue begins a sequential "squeezing" of the bolus against the hard palate towards the pharynx. The lateral edges of the tongue are positioned against the alveolar ridge to provide stability for the action of the midblade. The tongue forms a central groove during this time, which assists in propelling the bolus toward the pharynx. The oral transit phase of the swallow typically takes less than one and half seconds to complete. Oral transit is complete once the pharyngeal swallow is initiated or as soon as the bolus head crosses the rami of the mandible, as seen under videofluroscopy. Both the oral preparatory and oral transit phases of swallowing are under some form of volitional control in the adult swallow (Logemann, 1998).

The pharyngeal phase begins with activation of the pharyngeal reflexive response. Sequentially, the following events take place once the pharyngeal response is activated: elevation and retraction of the soft palate, superior and anterior motion of the hyolaryngeal complex, complete closure of the larynx at all three levels (true vocal folds, vestibular folds, and epiglottic retroflexion), opening of the upper esophageal sphincter, posterior movement of the base of tongue to accomplish contact with the bulging posterior pharyngeal wall, and superior to inferior constriction of the pharynx (Bosma, 1957; Frenckner, 1948; Harding, 1984; Negus, 1948; Perlman, 1994; Saunders, Davis, & Miller, 1951). These actions allow for a smooth transfer of the bolus through the pharynx without introduction of food or liquid into the airway. The pharyngeal phase of swallowing is typically accomplished in less than one second (Logemann, 1998).

In the last phase of the swallow, food is moved through the esophagus. Esophageal transit is measured from the time when the bolus head enters the esophagus through the upper esophageal sphincter until it passes through the lower esophageal sphincter into the stomach. Esophageal transit may last between eight and 20 seconds depending on bolus and individual characteristics. Esophageal transit is accomplished through peristaltic contractions that propel the bolus towards the stomach (Logemann, 1998).

Infant Oral Preparatory and Transit Phases of Swallowing

An infant’s feeding skills develop rapidly during the first two years of life to allow for increasing sophistication for the types of nutrition available to them. Initially, infants take all of their calories in a liquid form requiring them to express liquid nutrition through a nipple (either mother’s breast or bottle) for the first 4-6 months of life. Intake of sufficient calories is necessary for growth and life.

An infant must be able to extract liquid from the bottle or breast and transfer it into the pharynx to accomplish the oral preparatory phase and oral transit phase of swallowing. Depending on the number of suckles/sucks used to extract bolus material, the infant may need to collect liquid until it is a sufficient volume to swallow. Liquid may be collected between the tongue and soft palate, on the posterior tongue, or in the valleculae. A swallow may be triggered from the valleculae in infants without it being considered disordered due to the anatomical configuration of the oral cavity (Logan & Bosma, 1967). Infants use either a suckling or sucking action on the nipple to accomplish initial bolus extraction. The two can be differentiated by their primary oral motor characteristics.

Suckling is a reflexive response that is present in healthy term infants. It is characterized by the following: loose upper and lower lip approximation around the nipple, effective intraoral seal achieved by tongue to hard palate compressing the nipple with stabilization of the nipple achieved by bilateral fat pads, wide mandibular excursions with tongue blade movements characterized by protrusion and retrusion, and tongue protrusions do not extend passed the labial border (Arvedson & Brodsky, 2002; Hall, 2000; Swigert, 1998). Suckling is the predominant pattern for nipple feeding from birth until approximately 5-6 months of age. In suckling the infant is expected to achieve suck swallow coordination in a 1:1 ratio. That is the infant is expected to have one suck, one swallow, and one breath per second (Hall, 2000). The continued posterior wavelike motion of the tongue present in suckling and sucking is responsible for oral transit in infants. The use of ultrasound revealed that the wavelike component of suckle/sucking occurs in the medial portion of the tongue. As the wave progresses posteriorly, it applies both negative and positive pressure on the nipple, which expresses milk towards the pharynx (Bosma, Hepburn, Josell, & Baker, 1990).

Sucking contrasts with the early suckling pattern in a number of ways. Sucking is understood to be the result of cortical control of the suckling reflex and reflects the infant's learned nipple feeding behavior. It typically appears after 5 months of age and differs from suckling in the following ways: lips are tightly approximated around the nipple, more loose approximation of the tongue to the hard palate, more graded/focused mandibular movements, and tongue movements are characterized by elevation and depression movements as opposed to protrusion and retrusion (Hall, 2000; Morris & Klein, 2000; Swigert, 1998).

There has been extensive research into the act of suckling/sucking. Ardran, Kemp, and Lind (1958), made perhaps the first observations of intraoral activity during suckling by examining cineradiographic films of breast and bottle-fed infants. They identified the tongue as the critical component in successful suckling/sucking and inferred that the tongue's "stripping" action was in fact more important than suction in transferring fluid into the oral cavity. That same year, Colley and Creamer (1958) utilizing a different methodology to determine which was more important in successful milk transfer (suction vs. compression) concluded that it was suction that was the most important feature for liquid expression. Suckling/sucking is now understood to require both compression of the nipple between the tongue and hard palate and expression of fluid through changes in intraoral pressure (Logan & Bosma, 1967). In 1968, Wolff identified a difference between nutritive suckling/sucking (used to ingest liquid, NS) and non-nutritive suckling/sucking (as done on the pacifier, NNS). He described NNS in a pattern of short bursts that utilized approximately two sucks per second and NS as a constant, slower, continuous pattern that utilized approximately one suck per second.

Several authors have investigated the developmental nature of suckling/sucking. Gryboski (1965) utilized manometry and a pulse wave technique to evaluate infant suckling/sucking. She reported that initial sucking bursts (in those with no previous feeding experience) were short and consisted of only three to four sucks. In contrast, those infants who had been feeding for several days produced longer sucking bursts of 10 to 30 sucks. Qureshi, Vice, Taciak, Bosma, and Gewolb (2002) looked at changes in rhythmic suckling during the first month of life and found that the stability of rhythmic suck and swallow is established by 40 weeks postmenstrual age. They also reported that the percentage of sucks per swallows in a 1:1 ratio decreased during the first month of life. These results suggest that infants adjust their suck to swallow ratio during the first month of life to improve feeding efficiency.

McGowan, Marsh, Fowler, Levy, and Stallings (1991) also reported on the developmental progression of NS in infants. They found that during the first year of life, the volume of liquid consumed per suck decreased with age and that paralleled the increasing suck rate that was observed with increasing age. Sucking rate increased from a mean of 77 sucks per minute at two months of age to more than 100 sucks per minute at nine months of age. Milk delivery also effects suckling/sucking frequency (Weber, Woolridge, & Baum, 1986). Bottle-fed infants were found to swallow with every suck unless the milk flow was restricted. With restricted milk flow, suckling/sucking and swallowing became less frequent.

Gewolb, Vice, Schweitzer-Kenney, Taciak, and Bosma (2001) studied 20 healthy preterm infants to determine the influence of oral feeding experience on the developmental acquisition of sucking/suckling rhythms. The authors found that the stability of sucking/suckling rhythm and the percentage of swallows in a run were correlated with post-menstrual age not postnatal age. This indicated that it was development (as measured by postmenstrual age) and not experience (as measured by postnatal age) that had the greatest influence on rhythmic suckling/sucking. Similar studies have echoed these initial results concluding that different aspects of the sucking pattern mature with advanced postmenstrual age in healthy preterms as compared to infants born following full-term gestation (Medoff-Cooper, Bilker, & Kaplan, 2001; Medoff-Cooper, Mcgrath, & Shults, 2002). An investigation into feeding efficiency concluded that differences in sucking rate were not responsible for differences in overall feeding effectiveness. However, those with what was determined to be “efficient” feeding utilized long, continuous sucking bursts that transferred larger volumes of milk compared to those “inefficient” feeders who utilized short sucking bursts that only transferred a very small amount of milk with each suck (Daniels, Casaer, Devlieger, & Eggermont, 1986).

Sensory innervation of the oral cavity. The oral cavity is rich with sensory innervation. Even though current understanding of suckling/sucking describes it as a reflexive activity, the sensory innervation of the oral cavity suggests that the oral phase of swallowing (suckling/swallowing in the infant model) would be modifiable based on any number of sensory variables. Altering the taste, temperature, viscosity, or method of bolus delivery (nipple characteristics) would appear to strongly influence the motor response of suckling/sucking in infants. It is the sensory responsiveness of the oral cavity in infants that allows for changes and modifications to the oral phase that may prove to be effective in preventing airway compromise during the swallow.

In the adult literature, it is well recognized that sensory characteristics strongly influence the oral phase of swallowing. The chemical and physical properties of what is to be swallowed have an effect on how the oral cavity prepares the bolus. This modulation of the oral cavity is possible because of the extensive innervation to the oral cavity and contiguous oropharynx. Cranial nerves V (trigeminal), VII (facial), IX (glossopharyngeal), and XI (accessory) all relay different afferent (sensory) information from the oral cavity to the nucleus tractus solitarius in the medulla. Each nerve is associated with a specific region in the oral cavity (Massey, 2006).

Afferent information regarding taste of the bolus material is relayed to the nucleus tractus solitarius (NTS) in the medulla. From the NTS, taste information is relayed to the thalamus, insula, and hypothalamus. The facial nerve (cranial nerve VII) relays information about taste from the anterior two thirds of the tongue. Taste sensation from the posterior third of the tongue is provided by the glossopharyngeal nerve (cranial nerve IX) and taste sensation from the lingual surface of the epiglottis is conveyed through the vagus nerve (cranial nerve X) (Massey, 2006).

The formation of the bolus and its oral transport are dependent upon a number of proprioceptive feedback signals. These various sensorium are provided by peripheral nerve connections to the central nervous system. The sensations of touch, temperature, pressure, pain, and proprioception are relayed to the brain primarily by the trigeminal nerve (cranial nerve V). The trigeminal nerve is responsible for relaying all of those different afferent signals from the majority of the oral cavity and the anterior two thirds of the tongue. Trigeminal fibers terminate in various locations depending on the carried signal: touch and pressure terminate in the main sensory nuclei, pain and temperature terminate in the spinal nuclei, and the stretch and proprioception fibers terminate within the mesencephalic nuclei. Cranial nerve IX (glossopharyngeal) is responsible for relaying somatic afferent signals from the posterior one third of the tongue and the faucial pillars to the NTS (Massey, 2006). Due to the complex sensory innervation of the oral cavity, the analysis of infant swallowing should recognize the possible contribution of the oral sensory input to modulating oropharyngeal swallowing function and protection of the airway.

Pharyngeal and Esophageal Stages of Infant Swallowing

The pharyngeal and esophageal stages of the infant swallow are similar to that of the adult pharyngeal and esophageal phases. A notable difference, however, is the frequency with which the infant swallow occurs. Infants swallow more frequently and with greater speed than their adult counterparts (Newman, Cleveland, Blickman, Hillman, & Jarmillo, 1991). Another slight difference is the typical presence of small volume residue in the valleculae after the swallow due to the more caudal positioning of the larynx in infants as compared to adults (Ardran & Kemp, 1970). It was previously thought that infants could breathe and swallow simultaneously due to the high position of the larynx in the infant (Negus, 1942). Current understanding of infant swallow physiology includes the recognition of a brief swallow apnea (Bu'Lock, Woolridge, & Baum, 1990; Kelly, Huckabee, Jones, & Frampton, 2007; Thach & Menon, 1985; Wilson, Thach, Bouillette, & Abu-Osba, 1981). In the infant under 12 hours old there are frequent simultaneous contractions in the esophagus with deglutition. These contractions occur less frequently in the infant aged just three days. The lower esophageal sphincter usually has poor tone and participates in transient relaxation outside of swallowing. These abnormalities most likely represent an initial incoordination of esophagus in response to swallowing and are seen less frequently with maturation (Gryboski, 1965).

Most recently, Weckmueller, Easterling, and Arvedson (2011), provided normative information from a preliminary temporal analysis of oropharyngeal swallowing function in infants and young children. They applied a series of temporal measures to previously collected videofluroscopic swallow studies in 15 “normally” swallowing pediatric individuals. Their subjects were divided into three groups based on delivery of liquid bolus. Their research provided descriptive data on normal swallowing function in children from two months to 48 months of age. The authors report no significant difference in any of the temporal measures across age group or by method of feeding. Overall, the subjects demonstrated pharyngeal transit times of less than 1 second (consistent with adult data).

Coordination of Sucking/Swallowing/Breathing

Infants are required to utilize a sophisticated, highly coordinated process of suckling/sucking, swallowing, and respiration to safely consume enough calories to support their rapid growth and development. The suck/swallow/breath ratio is typically 1:1:1. This requires that the infant suck/suckle the liquid from the nipple, swallow, and continue respiration in a rhythmic sequence. Interruption to that sequence can result in airway compromise. Infants are obligate nasal breathers and their suck/swallow/breath sequencing is typically described as follows: 1) Infant breathes in through their nose, 2) Suckle/Suck, 3) Swallow (with cessation of expiration due to complete closure of the larynx), and 4) Expiration (Bamford, Toak, & Gewolb, 1992). A minimal period of airway closure with complete cessation of respiratory flow with a mean of 530 milliseconds was observed in a study of 13 infants (Koenig, Davies, & Thach, 1990). A mature, coordinated suck, swallow, breath pattern is typically present in infants by 37 weeks postmenstrual age (Bu'Lock et al., 1990; Hanlon et al., 1997). Earlier work by Wilson et al. (1981) found considerable variability in the timing of the subsequent inspiration following swallow. Further, they reported the interval between closure of the larynx and subsequent inspiratory effort was related to the phase of respiration interrupted by the swallow. The time between inspiration and swallow was longer when the swallow was initiated during late inspiration or early expiration compared to swallows occurring during late expiration or early inspiration. Their work suggested independence of the respiratory timing from the swallowing timing. More recent work by Gewolb and Vice (2006) has indicated while suck and swallow rhythms mature at ~37 weeks post menstrual age, stability of respiration and swallow matures at a later time.

Kidder (1995) describes the different effects of swallowing on breathing in both adult and infant subjects. In adult swallowing, the generally accepted respiratory phase for swallowing is the expiratory phase. This breathing/swallowing relationship is generally thought to be part of the central swallow mechanism. Kelly et al. (2007), prospectively followed 10 healthy term human infants through the first year of life collecting a total of 15, 073 swallows over 10 assessments between 48 hours and 12 months of age. They reported that midexpiratory swallows were the dominant pattern of breathing-swallowing coordination during the first 48 hours of life. This pattern rapidly changed during the first week of life, with inspiratory-expiratory swallows dominating with increased age—particularly between nine and 12 months of age. They conclude that there are two distinct shifts in breathing-swallowing coordination during the first year of life. The first shift occurs after the first week of feeding with the majority of the swallows observed moving from expiratory-expiratory phase to swallows occurring in the inspiratory-expiratory phase. The second shift occurs between six and 12 months of age when the majority of swallows were then followed by expiration. These authors conclude that instead of an entrained coordination pattern for sucking, swallowing, and breathing— the coordination actually follows a predictable developmental pattern. Although these authors have provided the most recent inquiry into suck:swallow:breathe coordination, it is a topic that has garnered attention for many years.

Oommen, Clark, Pronske, Luna-Solarzano, and Peterson (1985) found a significant reduction in minute ventilation during continuous sucking as part of bottle-feeding. The reduction in minute ventilation was the result of reduced breathing frequency and a prolongation of the expiratory phase with shortening of the inspiratory phase during bottle drinking. Their observations were reported during the onset of bottle-feeding and the infants in their study had subsequent recovery with continuation of the bottle-feeding event. Bamford et al. (1992) also found a reduction in breathing rate and overall tidal volume at the onset of bottle-feeding. These authors also reported mild transient oxygen desaturations with initiation of bottle-feeding and that in neonates, less than 48 hours old, rhythmic swallowing is maintained at the sacrifice of normal, unlabored breathing.

While the majority of reporting authors agree that the development of stable suck, swallow, breath coordination is dependent on maturation, many infants are asked to perform this highly complex sequence prior to reaching 37 weeks post menstrual age and often without achieving resting respiratory stability. Infants born prematurely are sometimes encouraged to feed earlier than 37 weeks postmenstrual age due to pressures for discharge. Infants with poor respiratory stability despite reaching at least 37 weeks postmenstrual age are another vulnerable feeding population. Preterm infants and infants with respiratory impairment have been the subject of frequent investigation and have been shown to be particularly susceptible to the risk of prolonged hospitalization and reduced respiratory stability due to poorly coordinated oral feeding that results in airway compromise (Craig, Lee, Freer, & Laing, 1999; Daniels, Devlieger, Minami, Eggermont,

& Casaer, 1990; Gewolb et al., 2003; Miller & Kiatchoosakun, 2004; Oommen, 1988; Pridham, Sondel, Chang, & Green, 1992; Ross & Browne, 2002; Thoyre & Carlson, 2003; Timms, DiFlore, Martin, & Miller, 1993).

Swallowing Coordination in Infants with Respiratory Compromise

The infant with impaired respiratory functioning has particular difficulty organizing safe swallowing during bottle-feeding due to the requirement of swallow apnea to prevent airway compromise during the swallow. The pharynx serves as the dual passageway for both oxygen, on its way to the lungs, and formula, on its way to the stomach. As initially described, maintaining adequate oxygen in the body is necessary for survival. During the initial, continuous sucking phase there is a decrease in minute ventilation. Minute ventilation is a measure of the volume of gas inhaled or exhaled in one minute (Thach, 1990). Koenig et al. (1990) found that sucking does not interrupt breathing during non-nutritive sucking. However, during nutritive sucking there was an inverse relationship between minute ventilation and frequency of swallowing. They found that ventilation was essentially discontinued when infants swallowed with a frequency of 1.4 swallows per second. Recall from the previous discussion that a suck per swallow rate of 1:1 is considered to be the typical ratio for “normal” swallowing in infants (Qureshi et al., 2002).

Infants with respiratory compromise frequently have elevated respiratory rates and are taking more than one breathe per second. Their elevated respiratory rates represent an effort to supply sufficient oxygen to the body to maintain homeostasis despite disease state or anatomic abnormality that reduces oxygen intake. During feeding, infants with respiratory compromise frequently demonstrate an inability to competently close their airway to prevent laryngeal penetration or aspiration during the swallow (Miller, 2009). This airway incompetency is most likely the result of basal oxygen requirements precluding the complete closure of the airway during the swallow. Their respiratory compromised state also makes them less resistant to negative outcomes from laryngeal penetration/micro-aspiration and any degree of tracheal aspiration (Loughlin, 1989).

Assessing for Dysphagia in Pediatric Populations

When infants present with feeding difficulties, like those seen in infants with respiratory compromise, it is necessary to determine if airway compromise is a component of their feeding difficulties. Any difficulty in the oral preparatory, oral transit, pharyngeal, or esophageal phases of swallowing can be described as dysphagia. Instrumental assessment is necessary for definitive diagnosis of swallowing dysfunction (dysphagia) and aspiration (Lefton-Greif & McGrath-Morrow, 2007). Instrumental assessment for dysphagia might include the following: videofluoroscopic swallow study (VFSS) (also commonly known as the modified barium swallow study or MBS), fiberoptic endoscopic evaluation of swallowing with or without sensory testing (FEES of FEESST), ultrasonography, manometry, scintigraphy, and cervical auscaltation (Kramer & Eicher, 1993; Lefton-Greif, 2008; Newman, 2000; Tabaee et al., 2006). The most common instrumental assessment for dynamic assessment of oropharyngeal swallowing function in pediatric patients is VFSS (Lefton-Greif, 2008).

Goals of the pediatric VFSS include objective identification of oropharyngeal swallowing dysfunction, stressing the patient’s system attempting to recreate the dysphagia symptom, and evaluating the effectiveness of proposed treatment strategies (Benson & Lefton-Greif, 1994). This is accomplished by age/developmentally appropriate positioning of infants and children within a fluro suite in a specialized seating device that provides adequate trunk, neck, and head control. Presentation of test materials and viscosity of test materials are also presented in an age/developmentally appropriate format (Newman, 2000). Patients are traditionally positioned for a lateral view to begin the exam (Arvedson, 2008), during the exam patients may be repositioned for an anterior-posterior view if unilateral weakness is suspected.

Clinicians are advised to begin with a standard protocol and then individualize the materials and presentation according to the developmental level and swallowing disorder presented by each individual patient (Newman, 2000). Standardization of presented food/liquid textures is ideal to provide clinicians with a standard beginning point so that future studies can be compared (Benson & Lefton-Greif, 1994; Newman, 2000). For infants less than 6 months old, liquid from a bottle is presented. For infants older than 6 months and children, a modified version of the Logemman protocol is applied. These children consume liquid from a preferred method (in graded quantities if cup/straw drinking) and take pudding (pureed consistency) and cookie (solid consistency) from a spoon (Newman, 2000).

During the VFSS, clinicians are looking for abnormalities in the oral, pharyngeal, and esophageal phases of swallowing function. Typically, the following features are commented on in the report of the VFSS analysis:

1. Bolus extraction, formation, and propulsion
2. Spillover prior to the swallow
3. Oral residue
4. Oral transit time
5. Timing of pharyngeal swallow initiation
6. Strength of pharyngeal swallow
7. Pharyngeal residue
8. Presence of laryngeal penetration, aspiration, or nasopharyngeal backflow
9. Pharyngeal transit time
10. Opening of cricopharyngeal sphincter
11. Clearance of bolus through cervical esophagus
12. Retrograde movement through cervical esophagus to pyriform sinuses

Identification of laryngeal penetration, nasopharyngeal backflow, or aspiration of contrast material should not result in the termination of the VFSS, as these are merely symptoms of the underlying physiological issue.

The goal of the VFSS is not solely to confirm or deny the presence of dysphagia symptoms; instead, the goal is to determine the cause of the symptom and then identify the most appropriate treatment strategies to determine the safest and most appropriate intake of calories for infant and children. Depending on the dysfunction identified in either the oral, pharyngeal, or esophageal phase compensatory measures may be introduced. This may include either direct or indirect behavioral management techniques such as the following: modified adult compensations such as effortful swallow and other strategies/exercises that the patient must perform themselves during swallowing (direct) or changes in temperature, viscosity (thickened liquids), texture, or postural variations- such as side lying- that the infant or child does not to have to perform themselves (indirect). When choosing management strategies the clinician must be mindful of the developmental level of the patient as well as the patient’s cognitive status (Benson & Lefton-Greif, 1994; Newman, 2000).

The VFSS is the only instrumental assessment that provides visualization of the anatomy of the oral cavity, pharynx, larynx, and upper esophagus as well the function and integration of all four areas during the dynamic process of swallowing. This makes it ideal for providing the most thorough assessment of swallowing function and of compensatory measures to improve swallowing function in the pediatric population. It continues to be the gold standard for objectively assessing oropharyngeal swallowing function in this dynamic population (Benson & Lefton-Greif, 1994; de Benedictis et al., 2009; Kramer & Eicher, 1993; Newman, 2000).

Management of Pediatric Dysphagia

If during the modified barium swallow dysphagia is identified, the clinician must determine the safest, most effective way for the infant to intake sufficient calories (Lefton-Greif & McGrath-Morrow, 2007). Malnutrition is not an option in pediatric patients for a number of reasons. First, the greatest period of neurologic growth and maturation occurs in the last trimester of pregnancy and during the first two years of life. Proper and balanced nutrition is necessary to ensure appropriate growth and maturation during this critical period to prevent long-term developmental sequeale. Secondly, children are not capable of surviving a fast because of their limited stores of fat and energy. Therefore, initial treatment decisions must include the prognosis for safe and adequate oral intake. This leads the clinician and physician to consider the safest most effective method of caloric intake either by mouth with compensatory strategies (identified as effective on instrumental assessment) or temporary/permanent tube placement (Lefton-Greif & McGrath-Morrow, 2007; Newman, 2000).

Despite the critical importance of treatment for this population, limited information is available on the efficacy and/or the effectiveness of therapies used to treat infants and children with dysphagia. Most of the therapies and strategies used for treating pediatric dysphagia are modified versions of therapies used for the adult dysphagia patient. As an example, complete restriction of thin fluids is often recommended in adult and pediatric patients who demonstrate sufficient airway compromise during intake of thin fluids. However, a recent Cochrane Database review of the available literature on restriction of water intake in children experiencing thin liquid aspiration, revealed no studies that specifically addressed the issue in children. The authors conclude, “there is currently an absence of evidence to support a strict approach of full restriction of oral intake of water or support a more liberal approach of allowing oral water ingestion in children with primary aspiration of thin fluids” (Weir, McMahon, & Chang, 2005).

Thickened liquids as a treatment option. Increasing the viscosity of the swallowed liquid to either a nectar or honey consistency is a common treatment option to prevent airway compromise during the swallow. Increasing the viscosity of the swallowed liquid provides enhanced sensory information to the swallowing mechanism and, in theory, produces a favorable change in the oropharyngeal swallowing function. The use of thickened liquids has undergone much investigation in the adult literature. There have been mixed results regarding the effectiveness of this common treatment practice reported in the literature.

Some authors have reported changes in the oral and oral transit features of swallowing with increased bolus viscosity. Kendall, Leonard, and McKenzie (2001) reported more timely oral transit with less viscous boluses—indicating that increasing the viscosity of the swallowed bolus slows down the oral transit phase. Kendall et al. (2001) results confirmed earlier findings by Dantas et al. (1990) who reported delayed oral transit times with increased bolus viscosity. Pouderoux and Kahrilas (1995) found that increasing the viscosity of swallowed boluses increased the tongue propulsive and clearing pressures exerted by the oral tongue. They also found that the greatest influence of increased viscosity was on the anterior and middle parts of the tongue. Others have also reported changes in muscular lingual forces. Tsukada, Taniguchi, Ootaki, Yamada, and Inoue (2009) showed that the duration of the tongue and suprahyoid muscle forces were more forceful with increasing hardness of the swallowed bolus. Chi-Fishman and Sonies (2002) also demonstrated changes in the oral phase of swallowing during intake of spoon-thick consistencies as evidenced by greatest preswallow gestures and total oral movement durations. Examining the influence of viscosity on anteriorlingual forces during the oral stage of deglutition with increased viscosity, Miller and Watkin (1996) demonstrated significant increases in peak amplitude tongue forces. They concluded that bolus viscosity in addition to volume significantly influence the oral stage of swallowing function. Finally, Hamlet et al. (1996) investigated normal adult swallowing utilizing boluses of varying viscosity and found that oral discharge times were faster with increasing viscosity.

Researchers have also reported significant effects of increased viscosity on the pharyngeal and esophageal phases of swallowing. Kendall et al. (2001) reported a trend for prolonged upper esophageal sphincter opening with less viscous boluses but greater extent of opening with more viscous boluses. Dantas et al. (1990) showed delayed pharyngeal transit, increased duration of pharyngeal contraction, and prolonged and increased upper esophageal opening during swallows of boluses with increased viscosity. Taniguchi, Tsukada, Ootaki, Yamada, and Inoue (2008) found longer pharyngeal transit and pharyngeal clearance duration during swallows of increased viscosity. Ertekin et al. (1997) found faster durations of hyolaryngeal excursion and reduced duration of upper esophageal sphincter opening during swallows of increased bolus viscosity.

Examining the extent of swallowing apnea onset with increased viscosity, Hiss, Strauss, Treole, Stuart, and Boutilier (2004) found that the onset of swallowing apnea was initiated later as bolus viscosity increased. Butler et al. (2011) found that there was greater airway compromise noted during swallows of 2% and whole milk (more viscous fluids) as compared to airway compromise noted during swallows of water and skim milk as seen during FEES. Bisch, Logemann, Rademaker, Kahrilas, and Lazarus (1994) reported significantly reduced pharyngeal response time and duration of laryngeal elevation with increased viscosity in those classified as typically swallowing individuals. In individuals with dysphagia as a result of stroke, these authors found shorter pharyngeal delay times, prolonged upper esophageal opening duration, and shorter duration of tongue base to pharyngeal wall contact with increased bolus viscosity.

In a similar project, Lazarus et al. (1993) reported longer durations of base of tongue contact to posterior pharyngeal wall contact in both nonstroke subjects and patients with dysphagia as a result of stroke, and longer cricopharyngeal opening duration and lower swallow efficiency in the patients who had not experienced stroke. Clave et al. (2006) also reported improved swallowing function (less airway compromise) in individuals with dysphagia as a result of neurological impairment. Kim et al. (1994) found that as bolus viscosity increased, esophageal emptying rate decreased, but oropharyngeal emptying (rate at which the bolus moved through the mouth and pharynx) rates were not affected by viscosity. Finally, Raut, McKee, and Johnston (2001) examined the effect of bolus viscosity on swallowing function in healthy volunteers and they reported increased upper esophageal pressures on opening and increased intra-bolus pressures during esophageal transit. Additionally, they reported increased amplitude of the bolus wave and clearing contraction within the pharynx with increased bolus viscosity.

Other authors have reported no changes in oropharyngeal swallowing function despite increased bolus viscosity. Bilder, Dooley, and Valenzuela (1990) reported no change in esophageal peristalsis rates with increased viscosity over the effect of changing bolus volume alone. Kendall et al. (2001) reported no changes in timing of pharyngeal transit and hyoid elevation/rate/extent with increased viscosity. No significant differences found between oropharyngeal pressures during swallows of water and paste (Perlman, Schultz, & VanDaele, 1993). Butler, Postma, and Fischer (2004) found no difference in swallow apnea duration with increased bolus viscosity but did find a significant change in swallow apnea duration with increased bolus volume. Steele and Van Lieshout (2004) found no significant changes in tongue behaviors across swallows of thin, nectar, and honey consistency boluses. Finally, while Hamlet et al. (1996) found significant changes in the oral phase of swallowing between thin and paste swallows, they did not find any difference between thin and paste bolus consistency swallows for pharyngeal transit times.

Efficacy of thickened fluid use in patients with dysphagia. While there has been extensive research into the effects of thickened fluids on oropharyngeal swallowing function in adult populations, the evidence for thickened fluids in the pediatric population is lacking. Additionally, while the overriding thought among speech-language pathologists for many years has been that thickened fluids are safer, that notion has been shown to be false in recent studies. Protocol 201 is the largest randomized clinical trial for dysphagia treatment efficacy to date. In a recent summary of that work, it was reported that individuals who have dysphagia with aspiration who continue to aspirate despite thickened fluid intervention have more severe respiratory outcomes if they continue to aspirate with thickened fluids as compared to continuing to aspirate standard/thin fluids (Robbins & Hind, 2008).

The immature gut of the infant further complicates the use of thickened fluids. Tutor and Gosa (2012) described the dangers of utilizing thickening agents in young infants in their review on the topic of pediatric aspiration. They reported on two cases of fatal, late stage necrotizing entercolitis (NEC) in infants utilizing a carob bean gum to thicken their formula as a treatment for gastroesophageal reflux disease. More recently, the US Food and Drug Administration (FDA) advised against the use of Simply Thick Gel ©, a xanthan gum based food thickener, in preterm infants. The FDA's warning was issued after additional infants developed NEC and at least 2 other infants died after consuming formula thickened with Simply Thick Gel © to relieve aspiration as a result of dysphagia (Tutor & Gosa, 2012).

While thickened fluids initially seem like a relatively easy and effective way to improve swallowing function, recent evidence from Protocol 201 and anecdotal evidence reporting negative consequences and even death from the use of common thickening agents in infants leads the speech-language pathologist to carefully weigh the evidence in support of thickened fluids against the risks for negative outcomes. In adult populations, much work has been done to investigate the effects of thickened fluids on swallowing function. A large majority of the work reviewed in the above document was done on "normal" swallowing populations. Unfortunately, the same body of evidence does not exist for pediatric populations. Very few papers have been published on the effects of thickened liquids in the pediatric populations and none of the published information is on “typically” swallowing pediatric populations.

Evidence for thickened fluids in the pediatric population. Gosa et al. (2011) published results from an evidence based systematic review to examine the available literature on the popular treatment option commonly known as thickened liquids. They found 22 articles that met the inclusion criteria of their study. Of those 22 articles six addressed the question asking what is the effect of thickened liquids on swallowing function. The six articles reported mixed results with the majority reporting a reduction in penetration or aspiration with the use of thickened liquids but none of them explained the physiologic change that resulted in the reduction of penetration or aspiration in this population.

Five of the included articles in the evidence-based systematic review reported on the effects of thickened liquids on the presence of aspiration during the swallow and among the 121 participants from these five studies only 60 subjects had elimination of aspiration with the use of thickened liquids (Frazier & Friedman, 1996; Khoshoo, Ross, Kelly, Edell, & Brown, 2001; Mercado-Deane et al., 2001; Schroeder, Thakkar, Poznanovic, & Holinger, 2008; Sheikh et al., 2001). Two articles reported on laryngeal and tracheal penetration and found that 27 of the 36 subjects between the two papers had elimination of tracheal and/or laryngeal penetration with the use of thickened liquids (Khoshoo et al., 2001; Mercado-Deane et al., 2001). One of the six articles reported on nasopharyngeal reflux and found that there was elimination of nasopharyngeal reflux in both of the participants in their study (Kuroki, Ishikawa, Kurosaki, & Niimi, 1996).

Finally, one of the six articles attempted to explain the improvement in swallowing function and reported that there was elimination of delayed pharyngeal swallow initiation in two of the 10 subjects in their report (Frazier & Friedman, 1996).

Sixteen articles included in the evidence-based systematic review addressed the question examining whether or not there were any adverse effects reported in infants and children who utilized thickened liquids as a treatment for dysphagia. No adverse effects were reported in the 16 studies. It must be noted, however, that the subjects of the 16 studies were primarily healthy, infants receiving thickened liquids as a treatment for reflux, not dysphagia (Gosa et al., 2011).

Clinicians treating dysphagia in the pediatric population, faced with a scarcity of data regarding outcomes of commonly used therapies, must make management decisions based on experience, knowledge of typical feeding and anatomical development, modified practices developed for use in the adult population, and accepted practices within their individual institutions. This highlights the need for rigorous evaluation of popular treatment methods in pediatric dysphagia (Lefton-Greif & McGrath-Morrow, 2007). Unfortunately, the current evidence base is not sufficient to provide clinicians with the definitive information they need to ensure proper care and treatment of infants with dysphagia.

Chapter 3: Statement of the Problem

There are well-defined differences between the pediatric and adult swallow. The causes of dysphagia in infants and children are vastly different from the causes of dysphagia in adults. As a result, dysphagia treatments used for adult populations will not necessarily be as effective if used to treat dysphagia in pediatric populations. There is a paucity of data available to establish the efficacy of common treatment strategies used to prevent or reduce airway compromise for infants who present with dysphagia. While there are at least six published papers that report improvement in swallowing function with the use of thickened liquids, there are no published data defining the physiologic changes within the upper aerodigestive tract that result in improved swallow safety when infants are given thickened liquids (Gosa et al., 2011).

This research will add to the currently limited knowledge of pediatric dysphagia by providing documentation of how biomechanical structures in the upper aerodigestive tract respond to different viscosities of bolus material swallowed. While there are a few published papers that point to improved airway protection during swallows of thickened fluids in pediatric populations, this project will provide the first documentation of the physiologic adaptations responsible for improved airway protection with the application of thickened liquids (Gosa et al., 2011).

Research Question

Does changing the viscosity of a swallowed bolus differentially affect the swallowing physiology in infants with respiratory impairment?

Hypothesis

Changing the viscosity of a swallowed bolus will improve the safety of oropharyngeal swallowing physiology in infants with respiratory impairment by increasing the duration of the temporal aspects of the oral components of swallowing physiology.

Chapter 4: Research Design and Methods

Participants

A retrospective review of the medical records of patients ages 1 week to 3 months of age who were also referred for a modified barium swallow study (MBS) at LeBonheur Children's Hospital in Memphis, Tennessee during the years of 2008 and 2009 was performed. The age range was restricted based on the developmental patterns for coordinating breathing and swallowing identified in the work of Kelly et al. (2007) and the established feeding development hierarchy. In their paper, Kelly et al. (2007) identified four patterns of breathing and swallowing coordination that occur during the first year of human life. The first shift in breathing and swallowing coordination takes place at one week of age. From 1 week of age to 3 months of age, the breathing and swallowing coordination pattern is stable with the next shift occurring after six months of age. Also, between 4 and 6 months of age infants are typically introduced to spoon-feeding. To avoid the possible developmental influence of spoon-feeding and the influence of a shift in breathing and swallowing coordination, the age range was limited to 1 week to 3 months of age. In subject recruitment, the youngest infant identified was 3 weeks of age and the oldest infant identified was 3 months of age.

In total, 25 subjects were identified. Each subject was assigned a number to ensure anonymity. The patient's name, medical record number, and financial number were removed from all reviewable records to avoid possible identification. The subjects' primary diagnostic categories were identified. From that information, those with primary diagnoses that had an effect on respiratory functioning (such as bronchitis, bronchopulmonary dysplasia, respiratory failure, acute respiratory distress syndrome, croup, respiratory syncytial virus, pneumonia, atelectasis, asthma, pneumothorax, pulmonary hypertension, and cystic fibrosis) were identified. For inclusion, the subjects were required to have a MBS that identified dysphagia with score on the Penetration-Aspiration Scale of 2 or more on at least one swallow (Rosenbek, Robbins, Roecker, Coyle, & Woods, 1996). Based on the limited empirical evidence regarding normal swallowing in infants, airway compromise is not expected on videofluoroscopic imaging (Newman et al., 1991; Weckmueller et al., 2011). Therefore, any score above 1 on the Penetration-Aspiration Scale indicated swallow dysfunction by that criterion. Exclusion criteria included any infant with known neurologic impairment, any infant not at 38 weeks post-conceptual age, any infant with tracheotomy, and any infant with craniofacial anomaly. Gender differences in swallowing function have not been identified in infants; therefore gender did not serve as inclusion/exclusion criteria. Additionally, changes in swallowing function with the presence of a nasogastric (NG) tube have not been documented in this population; therefore presence on NG tube during MBS did not serve as inclusion/exclusion criteria.

The subjects are arranged in order of identification in Table 1. The table provides descriptive information including presence of NG tube, age at the time of the evaluation, respiratory diagnoses, number of swallows observed in each condition and total number of swallows observed.

Table 1

Selected Demographic Information for Each Subject

Subject Number	NG	Age	Respiratory Diagnosis	Swallows of Thin	Swallows of Nectar	Total Number of Swallows
1	+	1m	Pneumonia	5	5	10
2	-	2m	C Wheezing	5	5	10
3	-	1m	Pneumonia	5	5	10
4	-	2m	C Congestion	5	5	10
5	-	1m	C Congestion	5	5	10
6	-	2m	Wheezing	5	5	10
7	+	2m	Respiratory Distress	5	5	10
8	-	2m	C Wheezing	5	5	10
9	-	3w	Respiratory Distress	5	5	10
10	-	2m	Dyspnea	5	5	10
11	+	1m	Respiratory Distress	5	5	10
12	-	2m	C Wheezing	5	5	10
13	-	3m	C Wheezing	5	5	10
14	-	3w	Respiratory Distress	5	5	10
15	-	1m	LLL Atelectasis	5	5	10
16	+	1m	Pneumonia	5	5	10
17	-	1m	C Wheezing	3	3	6
18	+	2m	Respiratory Distress	4	3	7
19	-	1m	Respiratory Distress	5	5	10
20	-	1m	C Congestion	5	5	10
21	-	1m	C Congestion	5	5	10
22	-	3m	C Lung Disease	4	5	9
23	+	1m	RSV	5	5	10
24	-	1m	Bronchiolitis	5	5	10
25	-	2m	RSV	5	5	10

Note. M = Month; W = Week; C = Chronic; LLL = Left Lower Lobe; RSV = Respiratory Syncytial Virus

There were 11 female subjects and 14 male subjects included in this study. The mean age of the 25 subjects was 5.84 weeks (standard deviation of 2.67 weeks). Six of the 25 subjects (24%) had an NG tube in place during their MBS study. Each subject provided 3-5 swallows of thin and 3-5 swallows of nectar thickened barium for review for a total of 121 swallows of thin and 121 swallows of nectar thickened barium. In total, the 25 subjects included in this project provided 242 swallows for analyses. The most common respiratory diagnosis among the 25 subjects was respiratory distress (6/25, 24%). Chronic wheezing (5/25, 20%) and chronic congestion (4/25, 16%) were also frequently diagnosed among these subjects.

Reliability, Validity, and Variables

Two independent analysts individually assessed the swallows obtained from the MBS with frame-by-frame analyses utilizing QuickTime 7 © software. Fifteen different swallowing variables were chosen for review based on previous videofluoroscopic analyses of infant swallowing function (Mercado-Deane et al., 2001; Newman et al., 1991; Weckmueller et al., 2011). The following parameters were measured for each swallow:

- *Number of sucks per swallow* - Downward motion of mandible to mandible returning to neutral position as one suck.
- *Suck time* - Begin with frame at initiation of downward mandibular movement – End with frame at initiation of base of tongue propulsion. Suck time is difference between these two measures.
- *Oral transit time* - Begin with frame at initiation of base of tongue propulsion – End with last frame where bolus material is in the valleculae. Oral transit time is difference between these two measures.

- *Time to initiate velar movement* – Begin with first frame of posterior velar movement subtracted from the first frame of downward mandibular movement.
- *Collection of bolus before swallow* - Reviewer will identify where the bolus material was collected (posterior oral cavity-POC, base of tongue-BOT or valleculae-V, pyriform sinuses-PS, or other-O) at the onset of base of tongue propulsion.
- *Pharyngeal transit time* - Begin with last frame where bolus material is in the valleculae – End with last frame of cricopharyngeal opening. Pharyngeal transit time is difference between these two measures.
- *Duration of cricopharyngeal opening* - Begin with first frame of bolus head in the cricopharyngeal sphincter – End with first frame where cricopharyngeus is closed. Duration of cricopharyngeal opening is difference between these two measures.
- *Duration of pharyngeal constriction* - Begin with first frame of maximum pharyngeal constriction – End with onset of pharyngeal relaxation at the velum. Duration of pharyngeal constriction is difference between these two measures.
- *Time to laryngeal closure* - Begin with initiation of laryngeal closure with upward movement of the arytenoids – End with first frame of complete laryngeal closure. Time to laryngeal closure is difference between these two measures.
- *Duration of laryngeal closure* - Begin with first frame of complete laryngeal closure – End with first frame showing initiation of laryngeal opening. Difference between these two measures is duration of laryngeal closure.

- *Bolus position at initiation of laryngeal closure* - Reviewer will identify where the bolus material was collected (posterior oral cavity-POC, base of tongue-BOT or valleculae-V, pyriform sinuses-PS, esophagus- E, Other- O) at the onset of laryngeal closure.
- *Epiglottic Tilting* - Reviewer will mark Yes or No in response to whether the epiglottis retroflexes during laryngeal closure.
- *Nasopharyngeal Backflow* - Reviewer will mark Yes of No in response to whether bolus material entered the nasopharynx.
- *Residue* – Reviewer will mark Yes or No in response to whether there was residue after the swallow & will define where it was located (BOT or V, posterior pharyngeal wall- PPW, PS, or other-O). If the reviewer marks O, they will provide the anatomic location of the residue.
- *Penetration Aspiration Scale* – A standardized scale from Rosenbek et al (1996) will be used in the current study to describe the level of airway compromise during the swallow. Scores are defined in Table A1, found in Appendix A. Scores from the penetration aspiration scale have been found to approximate ordinality and intervality sufficiently to allow for interval level statistical analysis (McCullough, Rosenbek, Robbins, Coyle, & Wood, 1998).

Each analyst underwent a series of three, 1 and a half hours, training sessions. During these training sessions, the analysts were taught the definitions of all the intended measures to be collected and practiced collecting these measures with an independent expert analyst. Training videos were chosen at random from patients' ages 1 week to 6 months of age with no craniofacial anomaly that underwent videofluoroscopic swallowing study at LeBonheur Children's Hospital before December 2010 but did not meet inclusion criteria for the current study. The expert analyst had established intra-rater reliability before providing instruction and training to novice analysts.

Graduate student volunteers served as analysts because they had no previous experience with pediatric dysphagia. Theoretically, the graduate student volunteers did not introduce any clinical bias into their ratings because of their clinical inexperience. The expert analyst was a speech-language pathologist with the clinical distinction of Board Recognized Specialist in Swallowing and Swallowing Disorders and more than 5 years of clinical experience in the field of pediatric dysphagia diagnosis and management.

After completing training, the two analysts assessed 25 swallows with the established measures on two different occasions at least two weeks apart. Individual analysts were blinded to the ratings of the other analysts. The expert analyst independently assessed 10 of the original 25 swallows to provide a measure of validity for the two volunteer analysts. Calculation of the Pearson's *r* was used to establish inter and intra rater reliability for the two volunteer analysts for the 10 variables that met criteria for parametric analysis (number of sucks per swallow, suck time, oral transit time, initiation of velar movement, pharyngeal transit time, duration of cricopharyngeal opening, duration of pharyngeal constriction, time to laryngeal closure, duration of laryngeal closure, and score on the penetration-aspiration scale). Pearson's *r* provides a measure of the correlation between two variables. Pearson's *r* provides a measure of the strength of the correlation between two variables, in this case the variables being the analyses provided by the student analysts and expert analyst for measures providing interval or ratio level data (Hinkle, Wiersma, & Jurs, 2003a). Spearman's rank correlation coefficient was used to establish inter and intra rater reliability for the two volunteer analysts for four of the non-continuous variables (location of bolus before the swallow, location of bolus at initiation of laryngeal closure, presence of residue after the swallow and location of residue if present). These four non-continuous variables all represent ordinal data that can be ranked by their scores. Location variables were all ranked in order of appearance along the upper aerodigestive tract with lower location rankings representing material located closer to the oral cavity and higher location rankings representing material located closer to the hypopharynx and larynx. Presence of residue is dichotomous in nature (either yes it was present or no it was not present) but scores can be ranked with 1 (no residue) being more desirable than scores of 2 (residue). Spearman's rank correlation coefficient provides a measure of the strength of the correlation between two variables for ordinal data (Hinkle et al., 2003a). For the dichotomous variables of presence of epiglottic tilting during the swallow and nasopharyngeal backflow during the swallow, there was insufficient variability among the student analysts and the expert analyst to complete the Spearman's rho analysis. There was 100% agreement among the three analysts for those two dichotomous variables.

The two volunteer analysts achieved a correlation of 0.75 or higher for all statistical analyses. Each analyst's scores were also compared to the scores of the expert independent analyst with the Pearson's *r* and the Spearman's rank correlation coefficient respectively to establish validity of the volunteer analysts scores. The two volunteer analysts each achieved a correlation of 0.75 or higher with the expert independent analyst for both statistical analyses. Table B1 and Table B2, found in Appendix B, provide the individual scores for each of the reliability measures for both intra-rater and inter-rater reliability for training data.

Data Collection

The expert analyst reviewed the complete digital recordings of the identified subjects' MBS studies. The MBS studies were captured utilizing the KayPENTAX Digital Swallowing Workstation © and were all recorded at 30 frames per second. The first two swallows from each study were excluded due to the frequent changes in positioning that occur during the initial two swallows. The last three to five continuous swallows of thin liquid were copied for each subject and the analysts reviewed those swallows for the established parameters. The first two swallows from the nectar thickened liquid sample were also excluded, again due to the frequent changes in positioning that occur during the initial two swallows. The last three to five continuous swallows of nectar-thickened liquid were copied for each subject and the analysts again reviewed those swallows for the established parameters. The copied swallow data were combined into one digital file for review by the analysts. The sequences of thin and nectar thickened swallows were randomly ordered in the combined video file to prevent bias in reviewing from knowledge of whether the analysts were viewing thin or nectar thickened liquid swallows. In total 121 swallows of thin and 121 swallows of nectar thickened liquid barium were reviewed for a total of 242 swallows.

Analyst 1 reviewed the combined video file independently for the established swallow parameters. Twenty percent of the subjects were also reviewed by Analyst 2 and were compared between the analysts to determine inter-rater reliability. At least two weeks after the initial review, Analyst 1 reanalyzed 20% of the subjects to establish intra-rater reliability. The expert analyst provided the starting frame for each swallow (initiation of mandibular movement) in the sequence to ensure an accurate starting point for each swallow. Previous experience has shown that due to the continuous nature of sequenced swallows, it is common for analysts to confuse swallow number in the sequence and provide inaccurate data if not provided with a starting frame.

Clinical Standards for MBS at LeBonheur Children's Hospital

Established standards at LeBonheur Children's Hospital dictate that infants undergoing MBS study are seated, semi-upright, in a Tumbleform chair and are viewed in the lateral projection. A standard, clinical protocol is followed for all infants undergoing MBS at LeBonheur Children's Hospital. Each infant is presented with Varibar Thin Liquid Barium (target viscosity of 4 centipoise, viscosity range <15 centipoise) and then may be presented with compensatory, thickened liquid bariums if swallowing function observed indicates its use. Compensatory liquids are administered with nectar-thickened liquids (target viscosity of 300 centipoise, viscosity range 150-450 centipoise) first and then honey thickened liquids (target viscosity of 1500 centipoise, viscosity range 800-1800 cenitpoise) if warranted. All liquids are prepackaged with standard viscosity and manufactured by Varibar. This controls for any variability in liquid consistency presented. Liquids are offered from a Similac bottle with standard one-hole nipple. When thickened liquids are administered, a cross-cut or red fast flow nipple may be introduced if the infants oral-motor functioning is insufficient to extract the thickened liquid from the standard one-hole nipple. The change in nipple is documented in the written report and audibly on the audio-video record of the MBS and will be accounted for in data analyses. For the current project, both liquids (thin and nectar thickened) were administered from a standard one-hole nipple.

Statistical Analyses

Once data were collected they were entered into SPSS 20 for review. To determine whether there were changes in the ten continuous variables (number of sucks per swallow, suck time, oral transit time, initiation of velar movement, pharyngeal transit time, duration of cricopharyngeal opening, duration of pharyngeal constriction, time to laryngeal closure, duration of laryngeal closure, and penetration-aspiration scale score) observed when subjects were drinking thin liquid barium compared to when the subjects were drinking nectar thickened liquid barium dependent t-tests were conducted with a Bonferroni adjustment to the alpha level to control for Type I error rate. The univariate dependent t-tests were used as recommended by Huberty and Morris (1989) who argue there is insufficient evidence to support the notion that a multivariate test protects against Type I error across univariate post hocs using the nominal alpha level. The experiment-wise error rate was set at $\alpha_E = .15$ as recommended by Kirk (1982) to protect against Type II errors. Thus, the alpha level used for each of the 10 dependent t-tests was .015.

Univariate effect sizes were also calculated utilizing the Cohen's *d* statistic to determine the magnitude of the differences between the two groups. The penetration-aspiration scale was previously established as approximating ordinality and intervality sufficiently to allow for parametric analysis (Hinkle, Wiersma, & Jurs, 2003b; McCullough et al., 1998).

The non-parametric technique of chi-square testing was applied to determine if there were significant changes among the categorical variables (location of bolus before the swallow, location of bolus at initiation of laryngeal closure, and location of residue after the swallow) as viewed under two conditions: swallows of thin liquid barium and swallows of nectar thickened liquid barium. The experiment-wise error rate was set at $\alpha_E = .05$. The dichotomous (yes/no) variables (epiglottic tilt, nasopharyngeal backflow, and presence of residue after the swallow) were analyzed for significant changes between thin and nectar thickened liquid swallows with McNemar's chi-square test. The experiment-wise error rate was set at $\alpha_E = .05$.

Chapter 5: Results

General Overview of Results

As indicated in the previous chapter, three different analyses were performed to explore the data collected for this project. The majority of the analyses explore the relationship between oropharyngeal swallowing function and the viscosity of the liquid swallowed. The results are presented in order of analysis in this chapter. The first section provides details of the intra and inter rater reliability of the data. The second section provides the results from the dependent t-tests that were undertaken to determine the effect of nectar thickened liquids on the oropharyngeal swallowing variables of number of sucks per swallow, suck time, oral transit time, initiation of velar movement, pharyngeal transit time, duration of cricopharyngeal opening, duration of pharyngeal constriction, time to laryngeal closure, duration of laryngeal closure, and penetrations-aspiration scale scores. The third section details the effects of thickened liquids on the noncontinuous, categorical variables of bolus location before the swallow, location of bolus at initiation of laryngeal closure, and location of residue after the swallow. Finally, the fourth section reports the results of the changes observed in the dichotomous variables between the two conditions of thin swallows and nectar thickened swallows.

Reliability

Repeated viewing of the video file was allowed to ensure that each analyst had the opportunity to be as accurate as possible. Neither analyst knew if she was watching swallows of thin or nectar thickened liquid barium. The first analyst reviewed the entire data file once, waited two weeks, and then reviewed 20% of the original data again to provide a measure of intra rater reliability. The second analyst reviewed 20% of the original data, waited two weeks, and then reviewed the limited data again. Multiple viewings allowed computation of inter and intra rater reliability. Each of the two analysts reviewed the selected data on all of the 15 different variables. Each analyst was blinded to previous ratings and to ratings of the other analyst.

Pearson's product moment correlations (Pearson's r) were computed for all continuous (interval and ratio level) variables (number of sucks per swallow, suck time, oral transit time, initiation of velar movement, pharyngeal transit time, duration of cricopharyngeal opening, duration of pharyngeal constriction, time to laryngeal closure, duration of laryngeal closure, and score on penetration-aspiration scale). Spearman's rank correlation coefficients (Spearman's rho) were computed for non-continuous variables including bolus location at base of tongue propulsion, bolus location at initiation of laryngeal closure, presence of residue after the swallow, and location of residue after the swallow. For the dichotomous variables of epiglottic tilt and presence of nasopharyngeal backflow, again there was insufficient variability to perform the Spearman's rho analysis. As a result, analyses of crosstab measures from the descriptive data revealed 100% agreement for intra and inter rater reliability for these two variables. Correlations for inter rater reliability among the continuous variables ranged from $r = .829$ to $r = 1.00$ and correlations for intra rater reliability among the continuous variables ranged from $r = .847$ to $r = 1.00$ for Analyst 1 and from $r = .894$ to $r = 1.00$ for Analyst 2. Correlations for inter rater reliability among the noncontinuous variables ranged from $r_s = .783$ to $r_s = 1.00$ and correlations for intra rater reliability among the noncontinuous variables ranged from r_s =.753 to r_s = 1.00 for Analyst 1 and from r_s = .755 to 1.00 for Analyst 2. Tables C1 through C4 provide the individual scores for all of the reliability measures and can be found in Appendix C.

Analysis of Continuous Variables

Means were derived for the 10 dependent variables used for parametric analysis. Table 2 provides the mean of 10 variables providing either interval or ratio level data in this study.

Table 2

Mean and Standard Deviation of Parametric Variables for Swallows of Thin and Nectar-Thickened Liquids

Variable	**Mean for Thin**	***SD* for Thin**	**Mean for Nectar**	***SD* for Nectar**
Sucks/Swallow	1.445	0.612	2.832	1.378
Suck Time	0.960	0.450	1.931	0.986
Oral Transit Time	0.221	0.035	0.249	0.037
Time to Initiate Velar Movement	1.024	0.429	2.031	0.966
Pharyngeal Transit Time	0.257	0.064	0.245	0.068
C-P Opening Duration	0.284	0.053	0.264	0.051
Pharyngeal Constriction Duration	0.358	0.092	0.377	0.084
Time to Laryngeal Closure	0.129	0.047	0.128	0.051
Duration of Laryngeal Closure	0.435	0.117	0.429	0.086
Penetration-Aspiration Scale Score	1.434	0.408	1.160	0.289

Note. All time and duration measures in seconds; *SD* = standard deviation

To determine the significant changes observed in the 10 dependent variables as a result of the two viscosity conditions, dependent t-tests were conducted with $\alpha = .015$. In order to prevent alpha inflation at this level of the analysis a Bonferroni correction for multiple comparisons was applied (.15/10, $\alpha = .015$). Table 3 summarizes the findings for the individual measures by viscosity condition comparisons with dependent t-tests.

Figures 1-3 provide visual representation of the above data. Figure 1 provides an illustration of the means across the two experimental conditions for the variables of number of sucks per swallow, suck time, and oral transit time (significant oral features). It illustrates the increase in number of sucks per swallow and time spent sucking during the nectar thickened liquid intake. Figure 1 also emphasizes the slight increase in oral transit time during intake of nectar thickened liquids.

Table 3

Results of Dependent t-tests

	Mean Dif	Std. Dev	*t*	Std. Error Mean	95% CI
*Pair 1: Number of sucks per swallow (Thin - Necar)	-1.387	0.948	-7.316	0.190	[-1.778, -0.996]
*Pair 2: Suck time (Thin – Nectar)	-0.971	0.808	-6.010	0.162	[-1.305, -0.638]
*Pair 3: Oral transit time (Thin – Nectar)	-0.028	0.008	-3.330	0.008	[-0.045, -0.011]
*Pair 4: Time to velar movement (Thin – Nectar)	-1.007	0.791	-6.365	0.158	[-1.333, -0.680]
Pair 5: Pharyngeal transit time (Thin – Nectar)	0.012	0.061	0.964	0.012	[0.037, -0.014]
Pair 6: Cricopharyngeus opening duration (Thin – Nectar)	0.020	0.054	1.861	0.011	[0.042, -0.002]
Pair 7: Pharyngeal constriction duration (Thin – Nectar)	-0.020	0.083	-1.162	0.017	[0.015, -0.054]
Pair 8: Time to laryngeal closure (Thin – Nectar)	0.001	0.056	0.088	0.011	[0.024, -0.022]
Pair 9: Duration of laryngeal closure (Thin – Nectar)	0.006	0.118	0.244	0.024	[0.055, -0.043]
*Pair 10: Penetration-aspiration scale score (Thin – Nectar)	0.274	0.504	2.714	0.101	[0.482, 0.066]

Note. Dif = Difference; CI = Confidence Interval; *p < .015; df = (24).

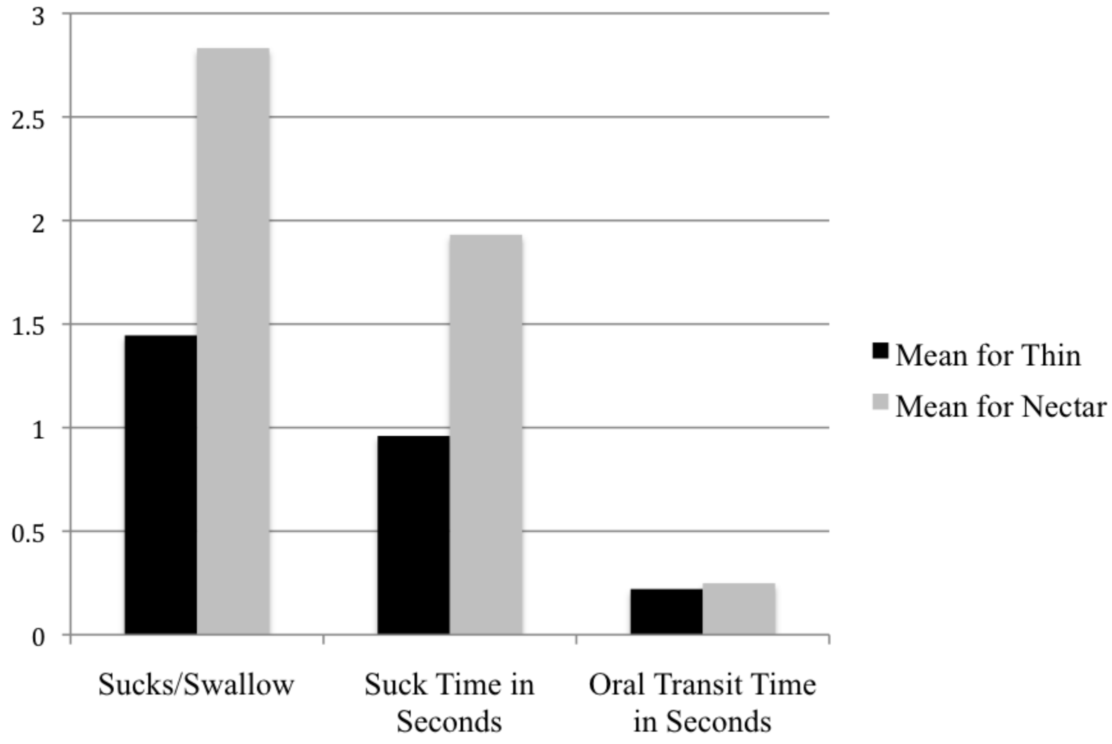

Figure 1. Means of oral phase variables significant for change between thin and nectar thickened liquid swallows.

Figure 2 provides a visualization of the difference in mean time to initiate velar movement between the two experimental conditions

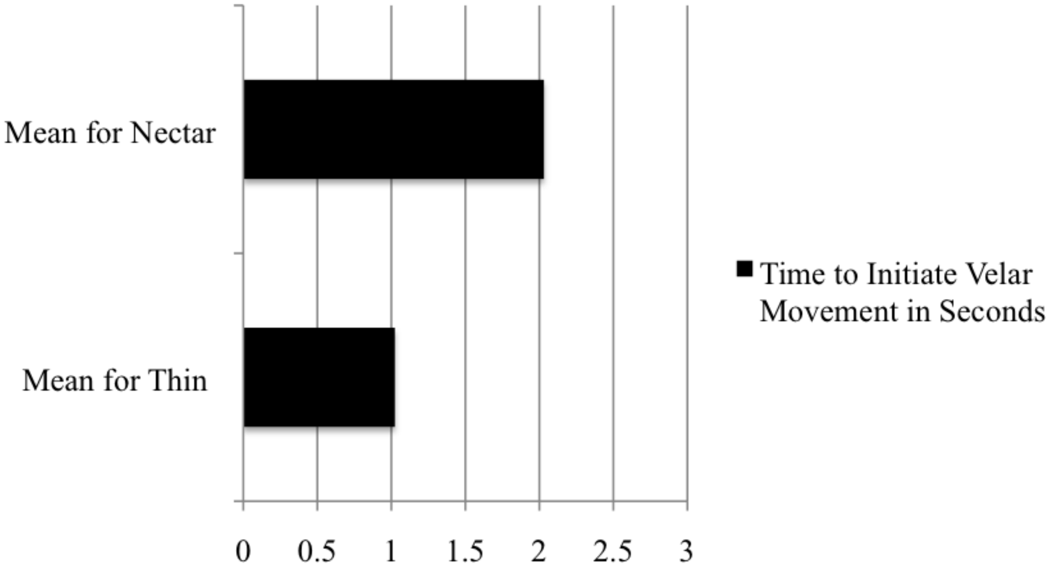

Figure 2. Mean time to initiate velar movement for swallows of thin and nectar thickened liquid barium

Figure 3 illustrates the relationship between the number of sucks per swallow and the initiation of velar movement for swallows of thin liquid barium and swallows of nectar thickened barium. There is an implied direct effect suggested by the increasing number of sucks per swallow on the initiation of velar movement. This implied effect from examining the raw data lead to post-hoc analysis with an additional Pearson's *r* to examine the correlation between these two variables during swallows of thin and during swallows of nectar. There was a strong correlation between number of sucks per swallow and time to initiate velar movement during swallows of thin ($r = 0.858$, n = 25, $p < .001$) implying a direct positive impact on the number of sucks per swallow and the time to initiate velar movement. There was a moderate correlation between the number of sucks per swallow and time to initiate velar movement during swallows of nectar ($r = 0.488$, n = 25, $p < .05$). The moderate correlation ($r = 0.488$) found between number of sucks per swallow and time to initiate velar movement during swallows of nectar thickened barium was smaller than the strong correlation ($r = 0.858$) observed between number of sucks per swallow and time to initiate velar movement for swallows of thin liquid barium. The difference in correlational strength between the two (thin and nectar) conditions is most likely the result of increased variance in number of sucks per swallow observed during the nectar thickened condition.

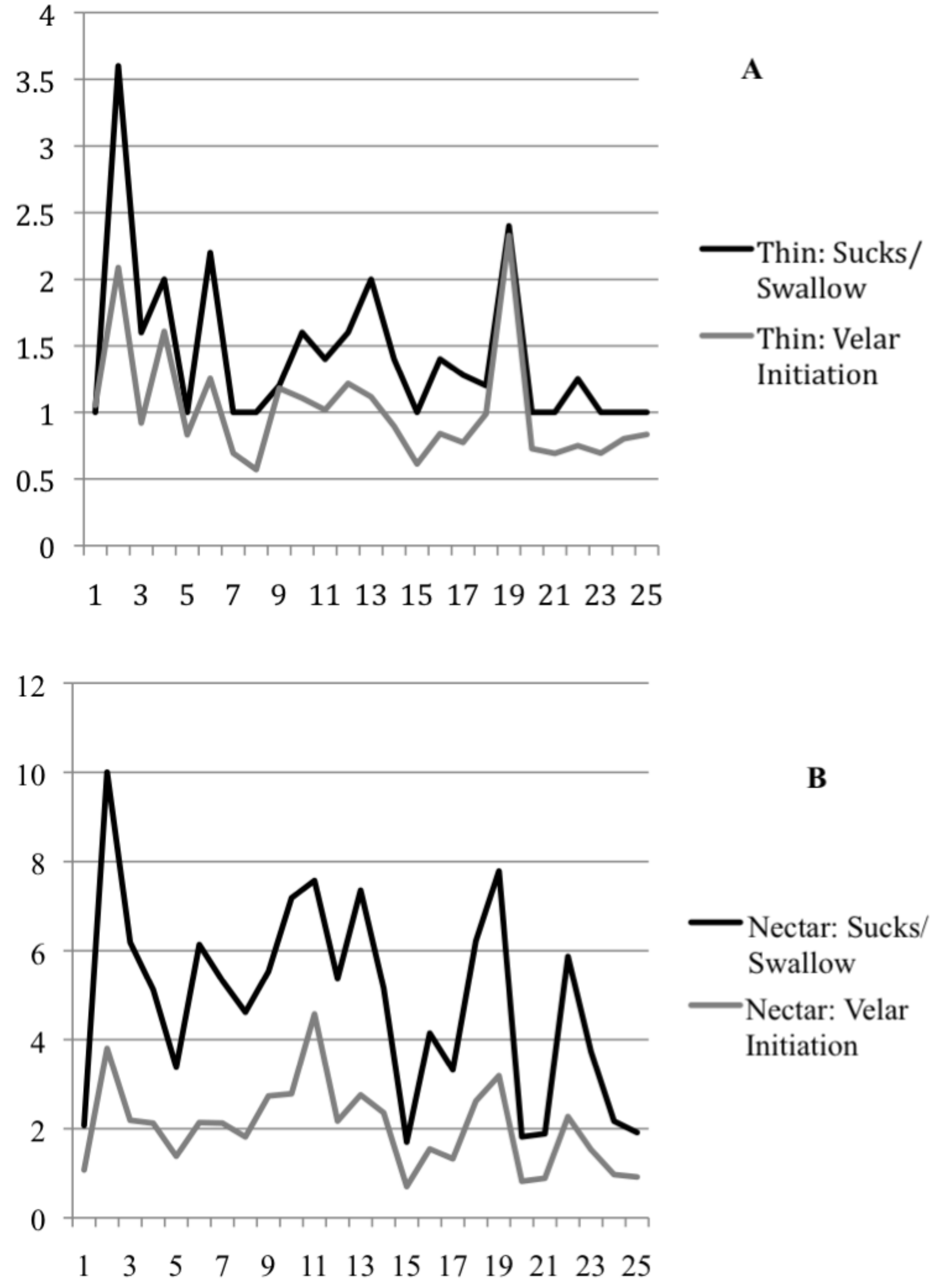

Figure 3. Direct relationship between subjects' mean number of sucks per swallow and subjects' mean time to velar initiation for (A) swallows of thin liquid barium and (B) nectar thickened liquid barium (n = 25).

Standardized effect sizes were calculated using Cohen's *d* procedure (*d* = pooled mean for paired samples / standard deviation of paired sample) (Hinkle, Wiersma, & Jurs, 2003c). Medium effect sizes were observed for changes in oral transit time (*d* = 0.667) and penetration aspiration scale scores (*d* = 0.544) between swallows of thin and nectar thick liquids, with there being a slightly longer oral transit time for swallows of nectar thickened liquids and slightly lower penetration aspiration scale scores (less severe airway compromise) during swallows of nectar thickened liquids. Very large effect sizes were observed for differences in the number of sucks per swallow (*d* = 1.463), average suck time (*d* = 1.202), and time to velar movement (*d* = 1.273). There were nearly 1.5 standard deviations more sucks per swallows, approximately one standard deviation difference with longer average sucking time, and approximately one standard deviation difference with longer time to initiation of velar movement for swallows of nectar thickened liquid as compared to swallows of thin liquid.

Analysis of Categorical Variables

The categorical variables of bolus location before the swallow, location of bolus at initiation of laryngeal closure, and location of residue after the swallow were analyzed for differences between the two levels of viscosity with the non-parametric technique of chi-square testing. The only significant variable identified by this procedure was the location of the bolus before the swallow. When infants took thin liquid, the bolus was most frequently held in the posterior oral cavity (64%) before the swallow. The bolus was also observed less frequently between the base of tongue and valleculae (26%) and in the pyriform sinuses (10%) before the swallow. In contrast, during swallows of nectar thickened liquid the bolus was most frequently observed between the base of tongue and the valleculae (45%) before the swallow. The bolus was less frequently seen in the pyriform sinuses (26%) and in the posterior oral cavity (29%) before the swallow during intake of nectar thickened liquids.

Analysis of Dichotomous Variables

The three dichotomous variables in this analysis were 1) presence of epiglottic tilt (yes or no), 2) presence of nasopharyngeal backflow (yes or no), and 3) presence of residue after the swallow (yes or no) and they were analyzed for differences among conditions with the non-parametric technique of McNemar chi-square testing. There was a significant difference ($p < .001$) noted for the variable of presence of residue after the swallow between the two conditions of thin and nectar thickened liquid swallows. During swallows of thin liquid, nearly 44% of swallows left residue somewhere in the upper aerodigestive tract. In contrast, there was a significantly greater percentage (nearly 80%) of residue after the swallow during swallows of the nectar thickened liquid. Epiglottic tilt, as seen in the adult swallow with complete retroflexion of the epiglottis over the laryngeal inlet during the height of the swallow, was not observed in either condition (swallows of thin or nectar thickened liquid) in this analysis. Nasopharyngeal backflow was seen in only 8 of the 121 swallows observed with thin liquid and in only 5 of the 121 swallows observed with nectar thickened liquid.

Chapter 6: Discussion

Points of Discussion

This study sought to determine the physiologic effects of providing thickened fluids to infants with dysphagia as a result of respiratory compromise. This study utilized frame-by-frame analysis of previously recorded MBS studies to compare 15 different variables between swallows of thin liquid barium and swallows of nectar thickened liquid barium. In total, 7 of the 15 variables were found to be significantly different between swallows in the two different conditions. Number of sucks per swallow, suck time, oral transit time, time to initiate velar movement, penetration-aspiration scale scores, location of the bolus before the swallow, and presence of residue after the swallow were all found to be significantly different between swallows of thin liquid barium and swallows of nectar thickened liquid barium. This project represents the first effort to systematically describe the physiologic effects of providing thickened fluids as a treatment option for dysphagia among a homogenous group of infants. These results reinforce previously reported features of thickened fluids as a treatment option for dysphagia and also suggest alternate theories for the oral phase of swallowing in infants with dysphagia as a result of respiratory compromise.

Considerations of the Oral Phase

In this study, significant differences were found between swallows of thin liquid barium and swallows of nectar thickened liquid barium specifically in the oral phase of swallowing. The number of sucks per swallows, overall time spent sucking, and oral transit times (see Figure 1) were increased for swallows of nectar thickened liquid barium. These results mirror reports from Kendall et al. (2001) and Dantas et al. (1990) who also found that increasing the viscosity of a swallowed bolus prolonged oral transit times.

These current results also contradict the popular notion that the suckling response in young infants is reflexive and unable to be modified until the infant reaches 3-5 months of age. As previously described, suckling is considered a reflexive response that is present in term infants. Suckling is described in popular literature as the predominant pattern for nipple feeding from birth until approximately 5-6 months of age. In suckling the infant is expected to achieve suck swallow coordination in a 1:1 ratio. That is the infant is expected to have one suck, one swallow, and one breathe per second (Arvedson & Brodsky, 2002; Hall, 2000; Swigert, 1998). Suckling's predictability and 1:1 ratio is a hallmark feature of this reflexive activity. In contrast, sucking is understood to be the result of cortical control of the suckling reflex and reflects the infant's learned nipple feeding behavior. Sucking has been thought to appear after 5 months of age and represent a more individualized nipple feeding response (Hall, 2000; Morris & Klein, 2000; Swigert, 1998).

The results from the current study suggest, however, that at least infants with respiratory impairment demonstrate the ability to modulate their suckling response much earlier than 5 months of age. In this study, the mean chronological age was 5.84 weeks and the average number of sucks per swallow during intake of thin liquid was more than 1 suck per swallow, which is counter to the popular literature that reports a 1:1 ratio of sucks per swallow, particularly in infants under 5 months of age. Additionally, when the higher viscosity bolus was introduced (nectar thickened liquid barium) the number of sucks per swallow increased to nearly 3 sucks per swallow, indicating that the infants made real time adaptations to their suckling pattern in response to sensory feedback from their oral cavity. This would imply a higher level of neural control over this “reflexive” response than the lower motor neuron level as described in the accepted clinical literature (Wolf & Glass, 1992).

Historical reports on infant suckling. These results do confirm earlier work from several researchers who have reported the ability of infants to alter their suckling behavior in response to changes in sensory input to the oral cavity at early chronological ages. Brassell and Kaye (1974) reported on altered suckling behavior in 36 human newborns in response to changes in non-nutritive stimuli. They found changes in pauses during suckling and number of sucks per suckling burst depending on the type of stimulus supplied. Sameroff (1973) explored the operant aspects of early sucking and concluded that it was the infant’s ability to adapt to any number of methods for providing nutrition that was reflexive. In his report, Sameroff (1973) found that even young infants (less than one month of age) utilize sensory information gained during sucking to modify the oral phase of swallowing to optimize their efficiency for caloric intake.

There is also extensive research into the oral sensory preference of newborn infants for “sweet” tastes. In the current project, the thin liquid barium and the nectar-thickened liquid barium had natural and artificial apple flavoring to aid in palatability. The previous work that reported on an infant’s preference for sweet further illustrates the infant’s ability to alter their suckling in response to characteristics of the bolus presented to the oral cavity. Weiffenbach and Thach (1973) describe the results of their experiment that confirm this now held truth. These authors demonstrated discrimination of water from a glucose solution in newborn, human infants. Their work confirms the sensitivity of the newborn for discrimination between these two substances based on sensory information provided from the tongue. Published in the same anthology is the work of Maller and Desor (1973), which describes the effect of taste in the oral behavior of human newborns. Their work confirms that the human newborn not only distinguishes sweet solutions from that of saline, but they also show a preference for the sweet solution by increasing their oral activity in response to that taste. The sweet preference is present very early in infancy and appears to be independent of experience. Finally, Nowlis (1973) reported on the effects of taste on lingual movements in newborn infants. He concluded that even newborn infants could modulate their oral behaviors to alter their intake of nutritive stimuli based on the sensory properties of that stimuli. Work into the effect of sensory recognition of “sweet” taste by newborn infants continued and more recent reports confirm the results of the earlier work (Birch, 1999; Crook & Lipsitt, 1976; Weiffenbach, 1977).

While popular understanding of suckling has been simplified to that of a purely reflexive activity consisting of a suck to swallow ratio of 1:1, the data from this study propose an alternate view. Infants with primary diagnoses that affect respiratory functioning, have a nearly 1.5:1 suck to swallow ratio during intake of thin fluids. When the viscosity of the fluid is increased, they immediately modulate their suck to swallow ratio to nearly 3:1 sucks per swallow. The change in number of sucks per swallow then results in longer time spent suckling and slightly longer oral transit times recorded during swallows of nectar thickened fluid in this cohort of infants. This modulation appears to be a direct result of altering the viscosity (changing the sensory characteristics) of the swallowed bolus and supports a higher neural level controlled oral response then what has been previously proposed in healthy newborns. This higher level neural controlled suckling response is in line with previous reports (described above) that demonstrate alterations in oral behavior with changes in either the oral stimulus or introduction of "sweet" tasting fluids.

Initiation of Velar Movement

Initiation of velar movement represents the onset of the pharyngeal phase of swallowing (Perlman, 1994). In the current project, initiation of velar movement was nearly two times slower for swallows of nectar-thickened barium as compared to swallows of thin liquid barium (see Figure 2). The increase in the number of sucks per swallow and subsequent prolongation of the sucking time resulted in an increased latency in activation of the pharyngeal response (see Figure 3). The difference in the initiation of the pharyngeal response between thin and nectar thickened liquid (Figure 3) seems to hint at the need for a critical bolus size to initiate the pharyngeal response.

These data suggest that despite the increased sensory information provided by the increased viscosity of the bolus, activation of the pharyngeal response as measured by velar initiation, was dependent on the accumulation of a specific bolus volume within the upper aerodigestive tract. The current retrospective analysis did not provide any information on the mean volume of bolus material swallowed during intake of thin and nectar thickened fluids. Additionally, the continuous, unrestricted intake of fluid during bottle drinking would make this theory difficult to test with current methods.

Previous work designed to discriminate between the effects of bolus volume and bolus viscosity in adult populations has shown differential effects of volume versus viscosity. Bilder et al. (1990) demonstrated that increasing bolus volumes improved the efficiency of esophageal transit but had no effect on esophageal peristalsis as compared to just increasing bolus viscosity. Butler et al. (2004) reported that swallow apnea duration increased with increased bolus volume but not with changes to bolus viscosity or taste. Miller and Watkin (1996) found no significant change in maximal lingual force amplitudes with increasing bolus volumes. Lazarus et al. (1993) reported that increasing bolus volume diminished pharyngeal delay times in patients with dysphagia as a result of stroke. In both stroke and nonstroke subjects, increasing bolus volume affected laryngeal closure durations, cricopharyngeal opening durations, and increased the duration of base of tongue to posterior pharyngeal wall contact during the pharyngeal phase of swallow (Lazarus et al., 1993). Additionally, activation of the pharyngeal response for saliva swallows is highly variable between healthy adults, but seems to be volume dependent based on individual characteristics of salivary rate (Rudney, Ji, & Larson, 1995).

One might also hypothesize that there is a critical mass that must be detected within the oral cavity to trigger the pharyngeal swallow response. Mass is a measure of an object’s resistance to the change of its speed. Density is a measure of the mass per unit volume. In the current study, the thin liquid barium had a density of 40% weight/volume with each 100 grams of the suspension containing 81 grams of barium sulfate. The nectar thick liquid barium also had a density of 40% weight/volume but with each 100 grams of the suspension containing only 40 grams of barium sulfate. While both materials had the same density, the mass per 100 grams was different with the thin liquid solution containing nearly twice the mass (81 grams) as the nectar thick solution (40 grams). If the pharyngeal swallow response is mass dependent, then it would fit in the current study that smaller volumes of thin liquid (that contained greater mass of barium sulfate) would trigger the swallow faster than the same volume of nectar thickened liquid (that contained less mass of barium sulfate). As a result, the infant would have to suck more to extract a larger volume of the nectar-thickened liquid to equal the same mass as the smaller volume of the thin liquid.

The previously discussed reports (Bilder et al., 1990; Butler et al., 2004; Lazarus et al., 1993; Miller & Watkin, 1996; Rudney et al., 1995) all indicated significant changes to the pharyngeal and esophageal phases of swallowing with increased bolus volume. However, it is unclear if these researchers controlled for changes in mass with changes in volume. Results from these papers point to differential effects of increasing bolus volume on the pharyngeal and esophageal phases of swallowing function in adult populations. Data from the present study raise the possibility of similar volume dependent effects in infant swallowing as has been reported in adult swallowing. Though bolus volume was not directly measured in the present study, it appears that a similar trend may apply in the infant swallow. This appears to be reflected in the prolonged velar initiation to start the pharyngeal phase with the nectar consistency liquid. The effect of mass versus the effect of volume is not readily apparent in the current data or in previously reported data.

Epiglottic Tilt

In the current report, there was 100% agreement between analysts for both conditions of thin and nectar swallows with regards to the absence of epiglottic tilting during the swallow. Additionally, analyses of the raw data reveals that Analyst 1 did not identify epiglottic tilting for any of 242 swallows observed (121 swallows of thin liquid barium and 121 swallows of nectar thickened barium). Classic reports of infant swallowing have reported epiglottic tilting over the laryngeal entrance during swallowing; as seen during adult swallowing (Logan & Bosma, 1967; Wolf & Glass, 1992). Considering the anatomic relationship and biomechanical forces believed to be responsible for epiglottic inversion during the adult swallow, it is not surprising that this feature would not be present in the infant swallow.

VanDaele, Perlman, and Cassell (1995) proposed that thyrohyoid approximation through thyrohyoid musculature is the primary effector in positioning the epiglottis below the horizontal plane. Further, thyrohyoid, geniohyoid, and mylohyoid appear to be the prime effectors of anterior hyoid bone movement and subsequently are the principle muscular components affecting epiglottic movements. The first epiglottic movement is achieved though the action of the tongue on the epiglottis and the subsequent secondary epiglottic movement is achieved by the biomechanical action of two lateral hyo-epiglottic ligaments acting on the lateral edges of the upper portion of the epiglottis.

In infants, the epiglottis may be omega shaped, more pliant and soft, and it has been seen to make direct contact with the soft palate in some cases due to the high laryngeal positioning, particularly in newborns. The epiglottis also has more direct contact with the base of tongue in infants and children again due to the superior positioning of the larynx in the pharynx (Kahane, 1983; Soloff, 1984). These anatomical and positional differences between the epiglottis of the infant and adult may explain the lack of epiglottic tilting reported in this project. These results confirm earlier observations of Rommel (2002) who also found that infants and children do not show consistent epiglottic tilting until after 5 years of age. Rommel proposed that the anterior movement of the arytenoids was sufficient for laryngeal closure in the smaller laryngeal vestibule found in younger children. Additionally, she proposed that epiglottic tilting may represent a maturational factor that changes with laryngeal and pharyngeal growth.

Location of Bolus Before the Swallow and Penetration-Aspiration Scale

There was a significant difference in the location of the bolus before the swallow with swallows of thin liquid barium versus nectar thickened liquid barium. During swallows of thin liquid barium, the bolus was most often held in the posterior oral cavity between the posterior portion of the tongue and the velum, in a more superior position along the upper aerodigestive tract and with further distance between the bolus and the larynx. In contrast, during swallows of nectar thickened liquid barium the bolus was most often held between the base of tongue and the valleculae. These data indicate that as the infant participates in a greater number of sucks per swallow during swallows of the nectar thickened liquid barium, the bolus migrates further down the upper aerodigestive tract towards the larynx. In theory this would seem to put the infant at greater risk for laryngeal penetration or aspiration during swallows of the nectar thickened liquid barium. However, scores from the Penetration Aspiration Scale between the two conditions did not support this theory. Scores from swallows of nectar thickened barium were significantly lower (representing less airway compromise) than scores from swallows of thin liquid barium.

There were more swallows that did not enter the airway (score of 1) during swallows of the nectar thickened liquid barium. Also evident in these data is a greater frequency of scores showing differing levels of laryngeal penetration (PAS scores 2-5) for swallows of thin liquid barium (32 total scores of 2-5) as compared to swallows of nectar thickened liquid barium (16 total scores of 2-4). A reduction in the frequency of airway compromise is clinically significant, especially in a population of infants already experiencing respiratory compromise.

A hypothesis for the improvement in airway protection despite collection of the bolus in closer proximity to the larynx before the swallow during intake of nectar thickened fluids may be found in the improved cohesiveness of the bolus with increased viscosity. The idea of improved swallowing safety with improved bolus cohesiveness as found with boluses of increased viscosity has been previously explored (Prinz & Lucas, 1997). Examining the variables responsible for mastication and safe swallowing in mammals, researchers proposed that boluses with greater viscosity have improved cohesion during the swallow and therefore result in a safer swallow or a swallow that does not result in airway compromise from either laryngeal penetration or aspiration.

Based on the initial data presented in this paper, it appears that improved cohesion of the more viscous (nectar thickened liquid barium) boluses is responsible for the statistically significant improvement in airway protection during the swallow, despite collecting the bolus closer to the larynx before the swallow.

Residue After the Swallow

Swallows of nectar thickened liquid barium had a greater percentage of residue present in the upper aerodigestive tract after the swallow as compared to swallows of the thin liquid barium. Nearly 44% of thin liquid barium swallows resulted in pharyngeal residue after the swallow. In contrast, 80% of nectar thickened liquid barium swallows resulted in pharyngeal residue after the swallow. These data seem to suggest that there is not modulation to the force of the pharyngeal swallow components despite the increased sensory component of the more viscous nectar thickened liquid barium. So, unlike the immediate modulation of the oral features of swallowing function to the increased viscosity of the nectar thickened liquid barium, it seems that the pharyngeal response is less receptive to the effects of increased viscosity.

Clinical Implications

As thickened fluids are known to be a common treatment strategy for infants with dysphagia, the data from the present study must be examined from a clinical perspective. Considered individually, some of the information could be misconstrued as undesirable. For example, on the surface, increased residue in the pharynx after the swallow with thickened liquids would be considered undesirable because of the assumption that it would increase an infant’s risk for aspiration after the swallow. However, when considered in context with other variables, the increase in residue during swallows of thickened liquids is not as alarming. Overall, there was a decrease in the mean penetration aspiration scale score for swallows of nectar thickened fluids. This negates the initial assumptions of increased airway risk during swallows of nectar-thickened fluids because of increased residue. Considered alone, the prolongation of the oral transit phase of the swallow appears to be a desirable influence on swallowing function. This presumed desirable influence must also be considered with respect to the infant's aerobic capacity. If increasing the number of sucks per swallow and prolonging the oral phase of the swallow creates a respiratory need that can not be met by the infant in a compromised respiratory state because of the increased work of sucking, then thickened fluids will not be a clinically effective treatment. If thickened fluids create unnecessary fatigue in this population then it can result in possible malnutrition from insufficient volume of intake.

The compelling clinical question that needs to be investigated is to determine whether or not providing thickened fluids is an effective treatment option for infants with dysphagia. The current project was not designed to answer that question. Instead, this project provides information regarding the physiologic changes that occur in the upper aerodigestive tract during swallows of thickened-fluids as compared to swallows of regular fluids. A prospective clinical project that examines the respiratory and anthropometric outcomes of infants who use thickened fluids as a treatment for dysphagia should provide an answer to that most important question.

Conclusions from Current Data

The most intriguing finding of the current study seems to be the effect of the thickened fluid on the oral stage of the swallow. By significantly increasing the number of sucks per swallow, prolonging the sucking time, slowing the time for oral transit, and thereby essentially prolonging the oral phase of each swallow, the infant reduces the frequency of swallows per minute. In essence, this seems to be what is most effective in reducing the episodes of airway compromise in this cohort of respiratory impaired infants.

Recall from previous discussion, that when healthy infants are participating in bottle-feeding there is a significant reduction in minute ventilation. Based on the inverse relationship between swallow frequency and minute ventilation (Koenig et al., 1990), reducing the frequency of swallowing during bottle-feeding should improve ventilation during feeding. Improving ventilation during bottle-feeding in infants with respiratory compromise should allow for safer swallowing by improving airway closure during the swallow. The improvement in Penetration Aspiration Scale scores seen during swallows of the thickened fluids supports the notion that decreasing swallow frequency improves the safety of swallowing function in infants with impaired respiratory functioning.

A final consideration of the current study is the absence of significant effects on the pharyngeal stage of swallowing function. Despite increasing the viscosity of the swallowed bolus, the variables measured during the pharyngeal stage of the swallow did not show significant differences between the two conditions. Pharyngeal transit times, duration of cricopharyngeal opening, duration of pharyngeal constriction, time to laryngeal closure, and duration of laryngeal closure were essentially unchanged between swallows of thin and swallows of nectar-thickened fluids. This lack of significant effects suggests that the pharyngeal phase of swallow is less responsive to changes in viscosity than the oral phase of swallowing.

Limitations and Future Directions

This was a retrospective study, which by design comes with inherent limitations. Frequent criticism of retrospective cohort studies include, bias in subject selection and bias from review of reported data. In this project, bias in subject selection was prevented by carefully defining the subjects of interest prior to beginning chart reviews for subject recruitment. Actual clips from the original MBS studies were copied and compiled in random order for review by analysts in order to provide original data for this project. This was done in order to avoid bias from previously reported data on the selected subjects. Randomization of the clips also helped to reduce bias from knowledge of whether the analyst was reviewing thin or nectar thickened fluid. The generalization of these data is limited because of the strict subject selection. However, the variables measured here could be applied to the oropharyngeal swallowing features of other cohorts. This would provide consistent data across populations for comparison and greater understanding of dysphagia symptoms and physiology among various diagnoses known to be associated with dysphagia in pediatric populations.

This project provides specific information on the effect of viscosity on oropharyngeal swallowing features in infants between 3 weeks and 3 months of age who present with dysphagia as a primary result of respiratory compromise. Among this homogenous sample, results indicate significant changes among the following variables: number of sucks per swallow, suck time, oral transit time, time to initiate velar movement, scores on the penetration aspiration scale, location of the bolus before the swallow, and presence of residue after the swallow. However, it does not provide information on the effect of bolus volume on these features and bolus volume has been shown to be significant in adult populations. Future projects should expand on the work presented here and also examine the effects of volume on these features of oropharyngeal swallowing function.

As the physiologic effects of thickened fluids on oropharyngeal swallowing function becomes evident, attention should turn towards determining the effects of various thickening agents on the developing guts of infants. This would help determine if the risks of providing thickened fluids outweigh the benefits to improved oropharyngeal swallowing function. Along this same line, future investigations should focus on recreating the significant effects of thickened fluids through altering the bolus delivery method (such as the nipple) to avoid introduction of foreign substances to the developing gut.

Finally, as it is known that infants are “learning to feed” during the first three years of life, it would be pertinent to determine the long term effects of prolonged thickened fluid use in infancy on the maturation of oropharyngeal swallowing function. As a follow up to that investigation, a well-designed prospective randomized clinical trial investigating the pulmonary and growth/nutrition outcomes of infants with dysphagia who use thickened fluids as a treatment option compared to infants who do not use thickened fluids would provide valuable outcome data.

References

Ardran, G. M., & Kemp, F. H. (1970). Some important factores in the assessment of oropharyngeal function. *Developmental Medicine and Child Neurology*, *12*(2), 158-166.

Ardran, G. M., Kemp, F. H., & Lind, J. (1958). A Cineradiographic study of breast feeding. *British Institute of Radiology*, *31*, 156-162.

Arvedson, J. C. (2008). Assessment of pediatric dysphagia and feeding disorders: Clinical and instrumental approaches. *Developmental Disabilities Research Reviews, 14*(2), 118-127.

Arvedson, J. C., & Brodsky, L. (2002). Anatomy, embryology, physiology, and normal development. In *Pediatric swallowing and feeding: Assessment and management* (2nd ed., pp. 13-79). Canada: Singular Publishing Group.

Bakwin, H. (1953). Infant feeding. *The American Journal of Clinical Nutrition*, *1*(5), 349-354.

Ball, J.W., Bindler, R.C., & Cowen, K.J. (2010). Alterations in respiratory function. In *Child health nursing: Partnering with children and families* (2nd ed., pp. 838-910). New York, NY: Pearson.

Bamford, O., Taciak, V., & Gewolb, H. (1992). The relationship between rhythmic swallowing and breathing during suckle feeding in term neonates. *Pediatric Research*, *31*(6), 619-624.

Benson, J., & Lefton-Greif, M. A. (1994). Videofluoroscopy of swallowing in pediatric patients: A component of the total feeding evaluation. In D. N. Tuchman, & R. S. Walter (Eds.), *Diagnosis of feeding and swallowing in infants and children: Pathophysiology, diagnosis, and treatment* (1st ed., pp. 187-200). San Diego, CA: Singular Publishing Group.

Bhatnagar, S.C. (2008). Axial-limbic brain: Autonomic nervous system, limbic system, hypothalamus, and reticular formation. In *Neuroscience for the study of communicative disorders* (3rd ed., pp. 353-377). Baltimore, MD: Wolters Kluwer Lippincott Williams & Wilkins.

Bilder, C. R., Dooley, C. P., & Valenzuela, J. E. (1990). Effect of bolus volume on the response of the human esophagus to a viscous bolus. *Scandinavian Journal of Gastroenterology*, *25*(5), 467-70.

Birch, L. L. (1999). Development of food preferences. *Annual Review of Nutrition*, *19*, 41-62.

Bisch, E., M., Logemann, J. A., Rademaker, A. W., Kahrilas, P. J., & Lazarus, C. L. (1994). Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. *Journal of Speech and Hearing Research, 37*, 1041-1049.

Bosma, J. F. (1957). Deglutition: Pharyngeal stage. *Physiological Reviews, 37*(3), 275-300.

Bosma, J.F., Hepburn, L.G., Josell, S.D., & Baker, K. (1990). Ultrasound demonstration of tongue motions during suckle feedings. *Developmental Medicine and Child Neurology, 32*(3), 223-229.

Brassell, W. R., & Kaye, H. (1974). Reinforcement from the sucking environment and subsequent modification of sucking behavior in the human neonate. *Journal of Experimental Child Psychology*, *18*(3), 448-463.

Brown, J. V., & Ross, E. S. (2011). Eating as a neurodevelopmental process for high-risk newborns. *Clinical Perinatology*, *38*(4), 731-743.

Bu'Lock, F., Woolridge, M. W., & Baum, J. D. (1990). Development of co-ordination of sucking, swallowing and breathing: Ultrasound study of term and preterm infants. *Developmental Medicine and Child Neurology*, *32*(8), 669-678.

Butler, S. G., Postma, G. N., & Fischer, E. (2004). Effects of viscosity, taste, and bolus volume on swallowing apnea duration of normal adults. *Otolaryngology Head and Neck Surgery*, *131*(6), 860-863.

Butler, S. G., Stuart, A., Case, D. L., Rees, C., Vitolins, M., & Kritchevsky, S. B., (2011). Effects of liquid type, delivery method, and bolus volume on penetration aspiration scores in healthy older adults during flexible endoscopic evaluation of swallowing. *The Annals of Otology, Rhinology, and Laryngology*, *120*(5), 288 295.

Chi-Fishman, G., & Sonies, B. (2002). Effects of systematic bolus viscosity and volume changes on hyoid movement kinematics. *Dysphagia*, *17*(4), 278-287.

Clave, P., de Kraa, M., Arreola, V., Girvent, M., Farre, R., Palomera, E., & Serra-Prat, M. (2006). The effect of bolus viscosity on swallowing function in neurogenic dysphagia. *Alimentary Pharmacology and Therapeutics*, *24*(9), 1385-1394.

Colley, J.R.T., & Creamer, B. (1958). Sucking and swallowing in infants. *British Medical Journal*, *2*(5093), 422-423.

Craig, C. M., Lee, D. N., Freer, Y. N., & Laing, I. A. (1999). Modulations in breathing patterns during intermittent feeding in term infants and preterm infants with bronchopulmonary dysplasia. *Developmental Medicine and Child Neurology*, *41*(9), 616-624.

Crook, C. K., & Lipsitt, L. P. (1976). Neonatal nutritive sucking: Effects of taste stimulation upon sucking rhythm and heart rate. *Child Development*, *47*(2), 518-522.

Daniels, H., Casaer, P., Devlieger, H., & Eggermont, E. (1986). Mechanisms of feeding efficiency in preterm infants. *Journal of Pediatric Gastroenterology and Nutrition*, *5*(4), 593-596.

Daniels, H., Devlieger, H., Minami, T., Eggermont, E., & Casaer, P. (1990). Infant feeding and cardiorespiratory maturation. *Neuropediatrics*, *21*(1), 9-10.

Dantas, R. O., Kern, M. K., Massey, B. T., Dodds, W. J., Kahrilas, P. J., Brasseur, J. G., Cook, I. J., & Lang, I. M. (1990). Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. *American Journal of Physiology*, *258* (5 Pt1), G675-681.

de Benedictis, F. M., Carnielli, V. P., & de Benedictis, D. (2009). Aspiration lung disease. *Pediatric Clinics of North America, 56*(1), 173-90.

Ertekin, C., Aydogdu, I., Yuceyar, N., Pehlivan, M., Ertas, M., Uludag, B., & Celebi, G. (1997). Effects of bolus volume on oropharyngeal swallowing: An electrophysiologic study in man. *The American Journal of Gastroenterology*, *92*(11), 2049-2053.

Frazier, J.B., & Friedman, B. (1996). Swallow function in children with Down syndrome: A retrospective study. *Developmental Medicine Child Neurology*, *38*, 695-703.

Frenckner, P. (1948). X-ray cinematografic demonstration of the swallowing procedure in normal and pathologic cases. *Acta Oto-Laryngologica, 36*(1), 83-84-90.

Gewolb, I. H., Bosma, J. F., Reynolds, E. W., & Vice, F. L. (2003). Integration of suck and swallow rhythms during feeding in preterm infants with and without bronchopulmonary dysplasia. *Developmental Medicine and Child Neurology*, *45*(5), 344-348.

Gewolb, I. H., & Vice, F. L. (2006). Abnormalities in the coordination of respiration and swallow in preterm infants with bronchopulmonary dysplasia. *Developmental Medicine and Child Neurology*, *48*(7), 595-599.

Gewolb, I. H., Vice, F. L., Schweitzer-Kenney, E. L., Taciak, V. L., & Bosma, J. F. (2001). Developmental patterns of rhythmic suck and swallow in preterm infants. *Developmental Medicine and Child Neurology*, *43*(1), 22-27.

Gosa M.M., Schooling T., & Coleman J. (2011). Thickened liquids as a treatment for children with dysphagia and associated adverse effects: A systematic review. *Infant Child and Adolescent Nutrition*. Published Online First: 5 May 2011. doi: 10.1177/1941406411407664

Gryboski, J. D. (1965). The swallowing mechanism of the neonate I: Esophageal and gastric motility. *Pediatrics*, *35*(3), 445-452.

Hall, K.D. (2000). Core knowledge. In *Pediatric dysphagia resource guide* (pp. 1-40) Clifton Park, NY: Singular Thomson Learning.

Hamlet, S., Choi, J., Zormeier, M., Shamsa, F., Stachler, R., Muz, J., & Jones, L. (1996). Normal adult swallowing of liquid and viscous material: Scintigraphic data on bolus transit and oropharyngeal residues. *Dysphagia*, *11*(1), 41-47.

Hanlon, M. B., Tripp, J. H., Ellis, R. E., Flack, F. C., Selley, W. G., & Shoesmith, H. J. (1997). Deglutition apnoea as indicator of maturation of suckle feeding in bottle-fed preterm infants. *Developmental Medicine and Child Neurology*, *39*(8), 534-542.

Harding, R. (1984). Function of the larynx in the fetus and newborn. *Annual Review of Physiology, 46,* 645-59.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003a). Correlation: A measure of relationship. In *Applied statistics for the behavioral sciences* (5th ed., pp. 95-120). Boston/New York: Houghton Mifflin Company.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003b). Introduction. In *Applied statistics for the behavioral sciences* (5th ed., pp. 1-16). Boston/New York: Houghton Mifflin Company.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003c). Hypothesis testing: Two-sample case for the mean. In *Applied statistics for the behavioral sciences* (5th ed., pp. 1-16). Boston/New York: Houghton Mifflin Company.

Hiss, S. G., Strauss, M., Treole, K., & Stuart, A. (2004). Effects of age, gender, bolus volume, bolus viscosity, and gustation on swallowing apnea onset relative to lingual bolus propulsion onset in normal adults. *Journal of Speech, Language, and Hearing Research*, *47*, 572-583.

Kahane, J. C. (1983). Postnatal development and aging of the human larynx. *Seminars in Speech and Language, 4*(3), 189-203.

Kelly, B.N., Huckabee, M.L., Jones, R.D., & Frampton, C.M.A. (2007). The first year of human life: Coordinating respiration and nutritive swallowing. *Dysphagia*, *22*(1), 37-43.

Kendall, K. A., Leonard, R. J., & McKenzie, S. W. (2001). Accommodation to changes in bolus viscosity in normal deglutition: A videofluoroscopic study. *The Annals of Otology, Rhinology, and Laryngology, 110*(11), 1059-1065.

Khoshoo, V., Ross, G., Kelly, B., Edell, D., & Brown, S. (2001). Benefits of thickened feeds in previously healthy infants with respiratory syncytial viral bronchiolitis. *Pediatric Pulmonology, 31*, 301-302.

Kidder, T. M. (1995). Esophago/pharyngo/laryngeal interrelationships: Airway protection mechanisms. *Dysphagia*, *10*(4), 228-231.

Kim, C. H., Hsu, J. J., O'Connor, M. K., Weaver, A. L., Brown, M. L., & Zinsmeister, A. R. (1994). Effect of viscosity on oropharyngeal and esophageal emptying in man. *Digestive Diseases and Sciences, 39*(1), 189-192.

Koenig, J. S., Davies, A. M., & Thach, B. T. (1990). Coordiantion of breathing, sucking, and swallowing during bottle feedings in human infants. *Journal of Applied Physiology, 69*(5), 1623-1629.

Kramer, S. S., & Eicher, P. M. (1993). The evaluation of pediatric feeding abnormalities. *Dysphagia*, *8*(3), 215-224.

Kuroki, H., Ishikawa, N., Kurosaki, T., & Niimi, H. (1996). Intractable wheezing in infants with nasopharyngeal reflux. *Acta Paediatrica Japonica*, *38*, 357-360.

Lazarus, C. L., Logemann, J. A., Rademaker, A. W., Kahrilas, P. J., Pajak, T., Lazar, R., & Halper, A. (1993). Effects of bolus volume, viscosity, and repeated swallows nonstroke subjects and stroke patients. *Archives of Physical Medicine and Rehabilitation*, *74*(10), 1066-1070.

Lefton-Greif, M. A. (2008). Pediatric dysphagia. *Physical Medicine and Rehabilitation Clinics of North America, 19*(4), 837-51, ix.

Lefton-Greif, M. A., & Arvedson, J. C. (2007). Pediatric feeding and swallowing disorders: State of health, population trends, and application of the international classification of functioning, disability, and health. *Seminars in Speech and Language*, *28*(3), 161-165.

Lefton-Greif, M. A., & McGrath-Morrow, S. A. (2007). Deglutition and respiration: Development, coordination, and practical implications. *Seminars in Speech and Language*, *28*(3), 166-179.

Logan, W.J., & Bosma, J.F. (1967). Oral and pharyngeal dysphagia in infancy. *Pediatric Clinics of North America*, *14*(1), 47-61.

Logemann, J.L. (1998). Anatomy and physiology of normal deglutition. In *Evaluation and treatment of swallowing disorders* (2nd ed., pp. 13-52). Austin, TX: Pro-Ed.

Loughlin, G. M. (1989). Respiratory consequences of dysfunctional swallowing and aspiration. *Dysphagia*, *3*(3), 126-130.

Maller, O., & Desor, J. A. (1973). Effect of taste on ingestion by human newborns. *Symposium on Oral Sensation and Perception*, *4*, 279-91.

Massey, B. T. (2006). Physiology of oral cavity, pharynx, and upper esophageal sphincter. *GI Motility online*, doi:10.1038/gimo2

McCullough, G. H., Rosenbek, J. C., Robbins, J. A., Coyle, J. L., & Wood, J. L. (1998). Ordinality and intervality of a penetration-aspiration scale. *Journal of Medical Speech Language Pathology*, *6*, 65-72.

McGowan, J. S., Marsh, R. R., Fowler, S. M., Levy, S. E., & Stallings, V. A. (1991). Developmental patterns of normal nutritive sucking in infants. *Developmental Medicine and Child Neurology*, *33*(10), 891-897.

Medoff-Cooper, B., Bilker, W. B., & Kaplan, J. M. (2001). Suckling behavior as a function of gestational age: A cross-sectional study. *Infant Behavior and Development*, *24*(1), 83-94.

Medoff-Cooper, B., McGrath, J. M., & Shults, J. (2002). Feeding patterns of full-term and preterm infants at forty weeks postconceptional age. *Journal of Developmental and Behavioral Pediatrics*, *23*(4), 231-236.

Mercado-Deane, M. G., Burton, E. M., Harlow, S. A., Glover, A. S., Deane, D. A., Guill, M. F., & Hudson, V. (2001). Swallowing dysfunction in infants less than 1 year of age. *Pediatric Radiology*, *31*(6), 423-428.

Miller, C. K. (2009). Updates on pediatric feeding and swallowing problems. *Current Opinion in Otolaryngology and Head and Neck Surgery*, *17*(3), 187-193.

Miller, J. L., & Watkin, K. L. (1996). The influence of bolus volume and viscosity on anterior lingual force during the oral stage of swallowing. *Dysphagia*, *11*(2), 117-124.

Miller, M. J., & Kiatchoosakun, P. (2004). Relationship between respiratory control and feeding in the developing infant. *Seminars in Neonatology*, *9*(3), 221-227.

Morris, S. E., & Klein, M. D., (2000). *Pre-feeding skills: A Comprehensive resource for feeding development* (2nd ed.). Tucson, AZ: Therapy Skill Builders.

Negus, V. E. (1942). The mechanism of swallowing: President's address. *Proceedings of the Royal Society of Medicine, 36*(2), 85-92.

Negus, V. E. (1948). The second stage of swallowing: Simple mechanism of swallowing. *Acta Oto-Laryngologica, 36*(1), 78-79-82.

Newman, L. A. (2000). Optimal care patterns in pediatric patients with dysphagia. *Seminars in Speech and Language*, *21*(4), 281-291.

Newman, L.A., Cleveland R.H., Blickman, J.G., Hillman, R.E., & Jaramillo, D. (1991) Videofluoroscopic analysis of the infant swallow. *Investigational Radiology*, *26*, 870-873.

Newman, L. A., Keckley, C., Petersen, M. C., & Hamner, A. (2001). Swallowing function and medical diagnoses in infants suspected of dysphagia. *Pediatrics, 108*(6), E106.

Nowlis, G. H. (1973). Taste-elicited tongue movements in human newborn infants: An approach to palatability. *Symposium on Oral Sensation and Perception*, (4), 292-310.

Oommen, M. P. (1988). Nipple units for newborn infants: A functional comparison. *Pediatrics*, *81*, 688-691.

Oommen, M. P., Clark, M. L., Pronske, M. L., Luna-Solarzano, H. G., & Peterson, M. D. (1985). Breathing pattern and ventilation during oral feeding in term newborn infants. *The Journal of Pediatrics*, *106*(5), 810-813.

Perlman, A. L. (1994). Normal swallowing physiology and evaluation. *Current Opinion in Otolaryngology & Head and Neck Surgery, 2*(0), 226.

Perlman, A. L., Schultz, J. G., & VanDaele, D. J. (1993). Effects of age, gender, bolus volume, and bolus viscosity on oropharyngeal pressure during swallowing. *Journal of Applied Physiology*, *75*(1), 33-37.

Pouderoux, P., & Kahrilas, P. J. (1995). Deglutitive tongue force modulation by volition, volume, and viscosity in humans. *Gastroenterology*, *108*(5), 1418-1426.

Pridham, K. F., Sondel, S., Chang, A., & Green, C. (1992). Nipple feeding for preterm infants with bronchopulmonary dysplasia. *Journal of Obstetric, Gynecologic, and Neonatal Nursing*, *22*(2), 147-155.

Prinz, J. F., & Lucas, P. W. (1997). An optimization model for mastication and swallowing in mammals. *Proceedings of the Royal Society B: Biological Sciences*, *264*(1389), 1715-1721.

Qureshi, M.A., Vice, F. L., Taciak, V. L., Bosma, J. F., & Gewolb, I. H. (2002). Changes in rhythmic suckle feeding patterns in term infants in the first month of life. *Developmental Medicine and Child Neurology*, *44*(1), 34-39.

Raut, V. V., McKee, G. J., & Johnston, B. T. (2001). Effect of bolus consistency on swallowing—Does altering consistency help? *European Archives of Oto-Rhino-Laryngology*, *258*(1), 49-53.

Robbins, J., & Hind, J. (2008). Overview of results from the largest clinical trial for dysphagia treatment efficacy. *Perspectives on Swallowing and Swallowing Disorders (Dysphagia)*, *17*(2), 59-66.

Rommel, N. (2002). Diagnosis of oropharyngeal disorders in young children: New insights and assessment with manofluoroscopy. Doctoral thesis. Katholieke Universiteit Leuven.

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.

Ross, E. S., & Browne, J. V. (2002). Developmental progression of feeding skills: An approach to supporting feeding in preterm infants. *Seminars in Neonatology*, *7*(6), 469-475.

Rudney, J. D., Ji, Z., & Larson, C. J. (1995). The prediction of saliva swallowing frequency in humans from estimates of salivary flow rate and the volume of saliva swallowed. *Archives of Oral Biology*, *40*(6), 507-512.

Sameroff, A. J. (1973). Reflexive and operant aspects of sucking behavior in early infancy. *Symposium on Oral Sensation and Perception*, *4*, 135-50.

Saunders, J. B., Davis, C., & Miller, E. R. (1951). The mechanism of deglutition (second stage) as revealed by cine-radiography. *The Annals of Otology, Rhinology, and Laryngology, 60*(4), 897-916.

Schroeder, J. W., Thakkar, K. H., Poznanovic, S. A., & Holinger, L. D. (2008). Aspiration following CO_2 laser-assisted supraglottoplasty. *Interntational Journal of Pediatric Otorhinolaryngology*, *72*, 985-990.

Sheikh, S., Allen, E., Shell, R., Hruschak, J., Iram, D., Castile, R., & McCoy, K., (2001). Chronic aspiration without gastroesophageal reflux as a cause of chronic respiratory symptoms in neurologically normal infants. *Chest*, *120*(4), 1190-1195.

Smith, C.A. (1959). Respiration: Neonatal aspects. In *The physiology of the newborn infant* (3rd ed., pp. 48-101). Springfield, IL: Charles C. Thomas Publisher.

Soloff, H. (1984). *The epiglottis in infants and adults: A study of linear measurements and the relationship between measurements in infant and adults groups.* Unpublished M.A., University of Memphis, TN.

Steele, C. M., & Van Lieshout, P. H. H. M. (2004). Influence of bolus consistency on lingual behaviors in sequential swallowing. *Dysphagia*, 19(3), 192-206.

Swigert, N.B. (1998). Anatomy and physiology. In *The source for pediatric dysphagia* (1st ed., pp. 13-23) U.S.A.: Linguisystems.

Tabaee, A., Johnson, P. E., Gartner, C. J., Kalwerisky, K., Desloge, R. B., & Stewart, M. G. (2006). Patient-controlled comparison of flexible endoscopic evaluation of swallowing with sensory testing (FEESST) and videofluoroscopy. *The Laryngoscope, 116*(5), 821-825.

Taniguchi, H., Tsukada, T., Ootaki, S., Yamada, Y., & Inoue, M. (2008). Correspondence between food consistency and suprahyoid muscle activity, tongue pressure, and bolus transit times during the oropharyngeal phase of swallowing. *Journal of Applied Physiology, 105*(3), 791-799.

Thach, B. T. (1990). Neuromuscular control of the upper airway. In R. C. Beckerman, R. T. Brouillette, & C. E. Hunt (Eds.), *Respiratory control disorders in infants and children* (pp. 47-60). Baltimore, MD: Williams & Wilkins.

Thach, B. T., & Menon, A. (1985). Pulmonary protective mechanisms in human infants. *American Review of Respiratory Disease, 131*(5), S55–S58.

Thoyre, S. M., & Carlson, J. (2003). Occurrence of oxygen desaturations events during preterm infant bottle feeding near discharge. *Early Human Development*, *72*(1), 25-36.

Timms, B. J., DiFlore, J. M., Martin, R. J., & Miller, M. J. (1993). Increased respiratory drive as an inhibitor of oral feeding of preterm infants. *Journal of Pediatrics*, *123*(1), 127-131.

Tsukada, T., Taniguchi, H., Ootaki, S., Yamada, Y., & Inoue, M. (2009). Effects of food texture and head posture on oropharyngeal swallowing. *Journal of Applied Physiology*, *106*(6), 1848-57.

Tuchman, D. N. (1988). Dysfunctional swallowing in the pediatric patient: Clinical considerations. *Dysphagia*, *2*(4), 203-208.

Tutor, J. D., & Gosa, M. M. (2012). Dysphagia and aspiration in children. *Pediatric Pulmonology*, *47*(4), 321-327.

VanDaele, D. J., Perlman, A. L., & Cassell, M. D. (1995). Intrinsic fibre architecture and attachments of the human epiglottis and their contributions to the mechanism of deglutition. *Journal of Anatomy*, *186*(Pt 1), 1-15.

Weber, F., Woolridge, M. W., & Baum, J. D. (2008). An ultrasonographic study of the organisation of sucking and swallowing by newborn infants. *Developmental Medicine and Child Neurology*, *28*(1), 19-24.

Weckmueller, J., Easterling, C., & Arvedson, J. (2011). Preliminary temporal measurement analysis of normal oropharyngeal swallowing in infants and young children. *Dysphagia*, *26*(2), 135-143.

Weiffenbach, J. (1977). Sensory mechanisms of the newborn's tongue. *Taste and Development: The Genesis of Sweet Preference.*Washington, DC: US Government Publishing Office.

Weiffenbach, J. M., & Thach, B. T. (1973). Elicited tongue movements: Touch and taste in the mouth of the neonate. *Symposium on Oral Sensation and Perception*, 4, 232-244.

Weir, K., McMahon, S., & Chang, A. B. (2005). Restriction of oral intake of water for aspiration lung disease in children. *Cochrane Database of Systematic Reviews (Online)*, (4), CD005303.

Wilson, S. L., Thach, B. T., Brouillette, R. T., & Abu-Osba, Y. K. (1981). Coordination of breathing and swallowing in human infants. *Journal of Applied Physiology*, *50*(4), 851-8.

Wolff, P.H. (1968). The serial organization of sucking in the young infant. *Pediatrics*, 42(6), 943-956.

Wolf, L. S., & Glass, R. P. (1992). Functional anatomy and physiology of the suck/swallow/breathe triad. In *Feeding and Swallowing Disorders in Infancy: Assessment and Management* (2nd ed., pp. 3-54) Tucson, AZ: Psychological Corporation.

Appendix A

Table A1

Description of Penetration-Aspiration Scale Scores

PAS Score	Description of Score
1	Material does not enter airway
2	Material enters the airway, remains above the vocal folds, and is ejected from the airway
3	Material enters the airway, remains above the vocal fold, and is not ejected from the airway
4	Material enters the airway, contacts the vocal folds, and is ejected from the airway
5	Material enters the airway, contacts the vocal folds, and is not ejected from the airway
6	Material enters the airway, passes below the vocal folds, and is ejected into the larynx or out of the airway
7	Material enters the airway, passes below the vocal folds, and is not ejected from the trachea despite effort
8	Material enters the airway, passes below the vocal folds, and no effort is made to eject

Source: Rosenbek, Robbins, Roecker, Coyle, & Woods, (1996)

Appendix B

Table B1

Intra-Rater Reliability of Analysts 1 and 2 Preliminary/Training Analyses

Parameter	Analyst	Statistic
Number of sucks per swallow	1	r = .954
Suck time	1	r = .806
Oral transit time	1	r = .997
Initiation of velar movement	1	r = .847
Pharyngeal transit time	1	r = .803
Duration of cricopharyngeal opening	1	r = *.833*
Duration of pharyngeal constriction	1	r = *.984*
Time to laryngeal closure	1	r = *.781*
Duration of laryngeal closure	1	r = *.802*
Pen-Asp Scale	1	r = .873
Location of bolus before swallow	1	r_s = 1.00
Location of bolus at initiation of laryngeal closure	1	r_s = .777
Epiglottic Tilt	1	100% Agreement
Nasopharyngeal Backflow	1	100% Agreement
Residue	1	r_s = .890
Loc residue	1	r_s = .833

(table continues)

Table B1 (Continued)

Intra-Rater Reliability of Analysts 1 and 2 Preliminary/Training Analyses

Parameter	Analyst	Statistic
Number of sucks per swallow	2	r = .909
Suck time	2	r = .781
Oral transit time	2	r = .995
Initiation of velar movement	2	r = .999
Pharyngeal transit time	2	r = .808
Duration of cricopharyngeal opening	2	r = .834
Duration of pharyngeal constriction	2	r = .951
Time to laryngeal closure	2	r = .857
Duration of laryngeal closure	2	r = .838
Pen-Asp Scale	2	r = 1.00
Location of bolus before swallow	2	r_s = .873
Location of bolus at initiation of laryngeal closure	2	r_s = .774
Epiglottic Tilt	2	100% Agreement
Nasopharyngeal Backflow	2	100% Agreement
Residue	2	r_s = .814
Loc of residue	2	r_s = .781

Note. r and r_s significant at $p < .01$

Table B2

Inter-Rater Reliability of Analysts 1 and 2 and Expert Analyst Preliminary/Training Analyses

Analyst	Partner	Parameter	Statistic
1	2	Number of sucks per swallow	$r = .909$
1	2	Suck time	$r = .847$
1	2	Oral transit time	$r = .935$
1	2	Initiation of velar movement	$r = .862$
1	2	Pharyngeal transit time	$r = .819$
1	2	Duration of cricopharyngeal opening	$r = .770$
1	2	Duration of pharyngeal constriction	$r = .972$
1	2	Time to laryngeal closure	$r = .852$
1	2	Duration of laryngeal closure	$r = .750$
1	2	Pen-Asp Scale	$r = .873$
1	2	Location of bolus before swallow	$r_s = .750$
1	2	Location of bolus at initiation of laryngeal closure	$r_s = .819$
1	2	Epiglottic Tilt	100% Agreement
1	2	Nasopharyngeal Backflow	100% Agreement
1	2	Residue	$r_s = .890$
1	2	Location of residue	$r_s = .786$

(table continues)

Table B2 (Continued)

Inter-Rater Reliability of Analysts 1 and 2 and Expert Analyst Preliminary/Training Analyses

Analyst	Partner	Parameter	Statistic
1	E	Number of sucks per swallow	r = .969
1	E	Suck time	r = .988
1	E	Oral transit time	r = .888
1	E	Initiation of velar movement	r = 1.00
1	E	Pharyngeal transit time	r = .915
1	E	Duration of cricopharyngeal opening	r = .792
1	E	Duration of pharyngeal constriction	r = .999
1	E	Time to laryngeal closure	r = .786
1	E	Duration of laryngeal closure	r = .945
1	E	Pen-Asp Scale	r = 1.00
1	E	Location of bolus before swallow	r_s = .764
1	E	Location of bolus at initiation of laryngeal closure	r_s = 1.00
1	E	Epiglottic Tilt	100% Agreement
1	E	Nasopharyngeal Backflow	100% Agreement
1	E	Residue	r_s = .802
1	E	Location of residue	r_s = .773

(table continues)

Table B2 (Continued)

Inter-Rater Reliability of Analysts 1 and 2 and Expert Analyst Preliminary/Training Analyses

Analyst	Partner	Parameter	Statistic
2	E	Number of sucks per swallow	$r = .841$
2	E	Suck time	$r = .870$
2	E	Oral transit time	$r = .935$
2	E	Initiation of velar movement	$r = 1.00$
2	E	Pharyngeal transit time	$r = .765$
2	E	Duration of cricopharyngeal opening	$r = .893$
2	E	Duration of pharyngeal constriction	$r = .992$
2	E	Time to laryngeal closure	$r = .918$
2	E	Duration of laryngeal closure	$r = .968$
2	E	Pen-Asp Scale	$r = 1.00$
2	E	Location of bolus before swallow	$r_s = .764$
2	E	Location of bolus at initiation of laryngeal closure	$r_s = 1.00$
2	E	Epiglottic Tilt	100% Agreement
2	E	Nasopharyngeal Backflow	100% Agreement
2	E	Residue	$r_s = .802$
2	E	Location of residue	$r_s = .802$

Note. r and r_s significant at $p < .01$

Appendix C

Table C1

Inter-Rater Reliability (Analysts 1 and 2) for Continuous Variables

Variable	Statistic
Number of Sucks per Swallow	$r = .997$
Suck Time	$r = .994$
Oral Transit Time	$r = .925$
Initiation of Velar Movement	$r = 1.00$
Pharyngeal Transit Time	$r = .829$
Duration of Cricopharyngeal Opening	$r = .955$
Duration of Pharyngeal Constriction	$r = .970$
Time to Laryngeal Closure	$r = .945$
Duration of Laryngeal Closure	$r = .980$
Score on Penetration-Aspiration Scale	$r = .866$

Note. All significant at $p < .01$

Table C2

Intra-Rater Reliability for Continuous Variables

Variable	Analyst	Statistic
Number of Sucks per Swallow	1	*r* = .997
	2	*r* = .997
Suck Time	1	*r* = 1.00
	2	*r* = 1.00
Oral Transit Time	1	*r* = .847
	2	*r* = .918
Initiation of Velar Movement	1	*r* = 1.00
	2	*r* = 1.00
Pharyngeal Transit Time	1	*r* = .964
	2	*r* = .960
Duration of Cricopharyngeal Opening	1	*r* = .956
	2	*r* = .966
Duration of Pharyngeal Constriction	1	*r* = .989
	2	*r* = .975
Time to Laryngeal Closure	1	*r* = .933
	2	*r* = .987
Duration of Laryngeal Closure	1	*r* = .969
	2	*r* = .894
Score on Penetration-Aspiration Scale	1	*r* = .915
	2	*r* = *.940*

Note. All significant at $p < .01$

Table C3

Inter-Rater Reliability (Analysts 1 and 2) for Non-Continuous Variables

Variable	Statistic
Bolus Location at Base of Tongue Propulsion	r_s = 1.00
Bolus Location at Initiation of Laryngeal Closure	r_s = .783
Presence of Residue after the Swallow	r_s = .905
Location of Residue after the Swallow	r_s = .909

Note. All significant at $p < .01$

Table C4

Intra-Rater Reliability for Non-Continuous Variables

Variable	Analyst	Statistic
Bolus Location at Base of Tongue Propulsion	1	r_s = 1.00
	2	r_s = 1.00
Bolus Location at Initiation of Laryngeal Closure	1	r_s = .770
	2	r_s = .788
Presence of Residue after the Swallow	1	r_s = .753
	2	r_s = .755
Location of Residue after the Swallow	1	r_s = .788
	2	r_s = .901

Note. All significant at $p < .01$