ABSTRACT

ULTRASONIC NORMATIVE DATA ON HYOID BONE DISPLACEMENT IN THREE AND FOUR YEAR OLD CHILDREN

By Susan Lyne Waizenhofer

The purpose of this study was to establish normative parameters regarding the total distance of hyoid bone displacement following discrete bolus sizes of puree and liquid in 3 and 4 year old children. Establishing normative parameters for hyoid bone displacement in preschool-aged children will assist in the safe and accurate diagnoses of pediatric dysphagia. Twenty-nine typically developing children were assessed via an ultrasonic procedure. Following the capture of a swallow, precise hyoid bone measurements were obtained through frame-by-frame analysis. Results indicated small variability in hyoid bone displacement across all bolus sizes and consistencies. A marginally significant interaction effect was present between bolus size and consistency regardless of age or gender differences; specifically, there was a strong interaction effect at 0.5 cc. Furthermore, the results demonstrated a significant gender effect characterized by greater hyoid bone displacement in female subjects.
ULTRASONIC NORMATIVE DATA ON HYOID BONE DISPLACEMENT IN THREE AND FOUR YEAR OLD CHILDREN

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Susan Lyne Waizenhofer

Miami University

Oxford, Ohio

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Advisor________________________________________

Dr. Donna Scarborough, Ph.D.

Reader________________________________________

Kelly Knollman-Porter, M.A.

Reader________________________________________

Dr. Joan Nolan, Ph.D.
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CHAPTER I

Introduction

Ultrasonography has been used in the medical field for a number of years as a diagnostic and clinical procedure. Ultrasound images are captured from the echoes of high frequency sound waves in real-time to display the movement of anatomic structures, muscles, and tissues (Bressman, Heng, & Irish, 2005). Once images are captured in real time, detailed measurements can be obtained through frame by frame analysis. Ultrasound is a non-invasive procedure that allows for extensive analysis of structures relative to deglutition (Lefton-Greif & Laughlin, 1996). The probe of the ultrasound is placed below the chin parallel or perpendicular to the midline of the face to capture the shadow of many structures including the tongue, hyoid bone, and mandible (Watkin, 1999). The hyoid bone is a point of attachment for various muscles involved in deglutition; therefore, providing a wealth of information concerning the swallowing patterns and safety of a patient during feeding (Chi-Fishman & Sonies, 2002). The anterior-superior movement of the hyoid bone is a critical component for laryngeal closure and opening of the pharyngoesophageal segment (Martin-Harris, Michel, & Castell, 2005).

Fiberoptic endoscopic evaluation of swallowing (FEES) and videofluoroscopic swallow studies (VFSS) are recognized as the preferred instrumental assessment tools to evaluate pediatric dysphagia (Colodny, 2002; Suiter, Leder, & Karas, 2009). However, due to continuous advancements in computer technology, ultrasound has become a distinguished procedure within the field of speech-language pathology. In contrast to VFSS, ultrasound provides an instrument free of ionizing radiation that can be used to evaluate treatment efficacy and thus may have a profound impression upon the field of speech-language pathology. Studies involving hyoid bone movement with ultrasound can provide critical information regarding the process of swallowing and has implications for diagnosis and treatment of those with swallowing disorders (Yang et al., 1997; Watkin, 1999).
Ultrasound studies have been used extensively to evaluate swallowing in adults and infants. In adults, ultrasound has been utilized as a research tool to provide discrete measurements of tongue, hyoid bone and laryngeal movements in both normal and disordered populations (Casas, Kenny, & Macmillan, 2003; Chi-Fishman, & Litvan, 1999; Chi-Fishman, Stone, & McCall, 1998; Chi-Fishman & Sonies, 2002; Frattali, Sonies; Ishida, Palmer, & Hiitemae, 2002; Kuhl, Eicke, Dieterich, & Urban, 2003; Peng, Jost-Brinkmann, Miethke, & Lin, 2000; Shawker, Sonies, Hall, & Baum, 1984; Shawker, Sonies, Stone, & Baum, 1983; Soder & Miller, 2002; Sonies, Parent, Morrish, & Baum, 1988). In addition, many ultrasound studies have been conducted to assess suckling behaviors in infants (Bosma, Hepburn, Josell, & Backer, 1990; Bu’Lock, Woolridge, & Baum, 1990; Jacobs, Dickinson, Hart, Doherty, & Faulkner, 2007; Miller & Kang, 2007; Smith, Erenberg, Nowak, Franken, 1985; Weber, Woolridge, & Baum, 1986), and to examine the prenatal development of the swallowing mechanism (Kalache, Franz, Chaoui, & Bollmann, 1999; Miller, Macedonia, & Sonies, 2006; Miller, Sonies, & Macedonia, 2003; Richards & Farah, 1994; Tez, Koktener, Aksoy, Turhan, & Dilmen, 2005; Wolfson & Laitman, 1990). However, limited research exists on the assessment of swallowing patterns via ultrasound in preschool to school-age children, which is surprising considering the advantages of using ultrasound as an objective tool over the use of videoradiographic examinations (i.e. x-rays).

To date, there are four ultrasound studies on school-age children with cerebral palsy (Casas, McPherson, & Kenny, 1995; Casas, Kenny, & McPherson, 1994; Kenny, Casas, & McPherson, 1989; Yang et al., 1997) and one pilot study conducted at Miami University (unpublished date, Scarborough, et al.) that investigated the swallowing patterns of both toddlers with low muscle tone and a control group of typically developing toddlers. Thus the proposed study will attempt to fill the substantial gap in literature concerning hyoid bone movement within typically developing preschool age children. The purpose of this study is to establish normative parameters regarding the total distance of hyoid bone displacement following discrete bolus sizes of puree and liquid. Establishing normative parameters for hyoid bone displacement in preschool-aged children will assist in the safe and accurate diagnoses of pediatric dysphagia.
CHAPTER II

Literature Review

Physiology of the Swallowing Mechanism: The Four Phases of Swallowing

Deglutition is the act of swallowing that begins with the preparation of food in the oral cavity and ends with esophageal passing of the food into the stomach (Dodds, 1989). Extensive research has cited deglutition as involving distinct phases, with the number dependent on the oral phase. The oral phase is often divided into two separate phases, including: 1) preparation of the bolus in the oral cavity, and 2) the propulsion of the bolus towards the oropharynx (Dodds, 1998; Logemann, 1998; Perlman, 1991). However, Martin-Harris et al. (2005) have proposed that the classification of deglutition into isolated phases is artificial due to the strong correlation between oropharyngeal events. The division of deglutition into distinct phases generates a descriptive view for understanding the physiology of the swallowing mechanism; however, it should be noted that the act of deglutition is an interdependent model where an overlap between phases exist (Martin-Harris et al., 2005). Thus, for the descriptive purposes of this paper, deglutition will be defined as 4 distinct phases: the oral preparatory phase, oral phase, pharyngeal phase, and esophageal phase (Dodds, 1989; Logemann, 1998).

The oral preparatory phase is highly individualized and dependent upon the volume and consistency of the bolus (Logemann, 1998). Upon introduction of food, the mandible elevates to close the oral cavity by contraction of the masseter, temporalis, and medial pterygoid muscles (Bass & Morrell, 1997). Glands produce saliva in response to sensory input, which contains digestive enzymes (i.e. ptyalin) to aid in bolus formation and the chemical breakdown of food (Pedersen, Bardow, Jensen, & Nauntofte, 2002). Throughout this stage, the lips are typically closed to maintain adequate lip closure; therefore, the oral preparatory phase requires nasal breathing. For liquid swallows, the bolus is positioned between the midline of the tongue and the anterior hard palate with the tongue elevated and in direct contact with the alveolar ridge and lateral alveolus to avoid anterior loss of the bolus (Logemann, 1998). Prior to initiating a swallow, a liquid consistency may also be held on the floor of the mouth anterior to the tip of the tongue. For thicker consistencies, such as pudding, the bolus may be held in the previously discussed positions; however, the individual may engage in increased manipulation of the
bolus and even mastication by moving the mandible and tongue in a rotary motion to form a cohesive bolus (Logemann). During mastication of solids, the tongue and buccal musculature simultaneously interact with the muscles of mastication to keep the bolus on the molar surface (Dikemann & Kazandjian, 2003). Upon formation of a cohesive bolus the oral transit stage is initiated and the tongue elevates to perform a sequential stripping action against the hard and soft palate; thus, propelling the bolus into the oropharynx (Dodds, 1989; Perlman, 1991).

The pharyngeal stage of deglutition in young and middle-aged adults is initiated when the head of the bolus reaches the anterior faucial arches and the swallow is triggered. However, for the geriatric population the normal swallow is triggered between the anterior faucial arches and the point where the mandible crosses the tongue base (Logemann, 1998; Mendell & Logemann, 2007; Robbins, Hamilton, Lof, & Kempster, 1992). The pharyngeal phase of the swallow functions to direct the bolus into the esophagus while protecting the airway from aspiration. Aspiration is defined as penetration of food, liquid, or secretions below the level of the true vocal folds (Logemann, 1997; Suiter et al., 2009). During the pharyngeal stage, the velum elevates to block the velopharyngeal opening and the superior constrictor muscle contracts to narrow the upper pharynx. At this time, the base of the tongue plunges the food into the pharynx and the hyoid bone and larynx are pulled into an anterior-superior position to foster airway protection and open the upper esophageal sphincter (UES) (Broniatowski, et al., 1999). As a result of this hyolaryngeal excursion, the epiglottis is depressed over the laryngeal aditus to protect the airway and divert the bolus into the pyriform sinuses (Perlman, 1991). The elevation of the hyolaryngeal complex during the pharyngeal phase plays an important role in airway protection. Decreased elevation will result in inadequate closure of the epiglottis over the trachea, increasing the risk of aspiration (Kuhl et al., 2003). In addition, the true vocal folds, false vocal folds, and the aryepiglottic folds adduct to close off the laryngeal valves. Pharyngeal peristalsis propels the bolus inferiorly towards the UES. The UES and cricopharyngeus relax in order for the bolus to pass into the esophagus (Perlman, 1991).

The esophageal stage begins when the bolus passes through the cricopharyngeal sphincter, terminating UES relaxation. During this stage, the bolus is carried toward the
stomach by gravity and peristalsis (Dodds, 1989). Speech-language pathologists regularly diagnose and treat disorders within the oral and pharyngeal phases of swallowing. However, to properly diagnose and manage pediatric dysphagia, the professional must not only understand the interaction within the phases of swallowing but possess adequate knowledge of normal embryological and fetal development of the swallowing mechanism.

**Embryological and Fetal Development of the Upper Digestive Tract**

Neuroembryology is the study of origin and development of the nervous system that extends to the seventh week of conception, when all anatomic structures in the brain have emerged (Bhatnagar, 2002). The upper aerodigestive tract is the primary location for respiration, phonation, and swallowing, making it the most complex neuromuscular unit in the body (Arvedson & Brodsky, 2002). During the fourth week of gestation, the neural crest cells located bilaterally along the neural tube begin to develop the 6 pharyngeal branchial arches. The branchial arches contribute to the formation of significant skeletal structures, cranial nerves, and muscles within the head and neck region that are responsible for speech and swallowing (Bhatnagar, 2002). During fetal maturation, upper aerodigestive tract functions become apparent, including: jaw, tongue, pharyngeal, and laryngeal movements (Miller et. al, 2003).

Early studies that investigated fetal swallowing utilized instrumental techniques that were harmful to the fetus, such as, exposure to radiation and the injection of radioactive substances into the amniotic cavity/fluid (Ross & Nijland, 1998). Although medical imaging has been utilized for many decades to assess sucking behaviors in infants, the harmful radiation from imaging poses a health threat and restricts the amount of observation (Bu’Lock et al., 1990; Jacobs et al., 2007). In 1978, a preliminary ultrasound study was performed to investigate fetal movement patterns (Birnholz, Stephens, & Faria, 1978); this study was later followed by Bowie and Clair (1982) to examine fetal swallowing via ultrasound. With the recent advances in ultrasound technology, extensive analysis and observation of primitive functions in the upper aerodigestive tract have become more precise and accurate (Kalache et al., 1999).

Miller and Kang (2007) describe non-nutritive sucking (NNS) as bursts of lingual activity followed by brief periods of inactivity. Through ultrasonic imaging, non-
nutritive sucking (NNS) has been observed in fetuses as early as 15 weeks gestation. As the fetus matures, the frequency and duration of these sucking patterns become increasingly complex (Miller et al., 2003). A recent study collected data on 62 healthy fetuses and observed the following lingual movements via ultrasound: a) forward thrust of the tongue to the lower labial margin as early as 15 weeks gestation, b) cupping of the tongue by 16 weeks, and c) suckling patterns similar of an infant during the 18th week of gestation (Miller). Stimulatory behavior was associated with suckling in 72% of the cases and manifested in various forms, such as: touching the face with a hand or arm and mouthing on extremities. Purposeful opening and closing of the jaw was observed at 17 weeks gestation while pharyngeal swallows were first observed at 15 weeks in utero. By 28 weeks gestation, the fetuses under study demonstrated more complex anterior-posterior suckling movements to propel the amniotic fluid into the oral cavity. Posterior elevation of the tongue reduced anterior loss of the bolus. Lingual movements then propelled the bolus towards the oropharynx, where a single pharyngeal contraction moved the bolus into the esophagus (Miller).

Sex differences were found in 85 healthy fetuses (mean gestational age 23 weeks 3 days) via ultrasound for oral-lingual, pharyngeal, and laryngeal movements. Males and females demonstrated similar physical growth patterns. However, female fetuses demonstrated more mature and complex motor movements, suggesting a gender difference in prenatal motor development that may influence post-natal oral motor skills (Miller et al., 2006). During the second trimester, female fetuses demonstrated more complex lingual movements during anterior-posterior sucking than males. However, during the third trimester the percentage of observed sucking movements for female subjects decreased while the male fetuses increased (males 76%, females 77%). Pharyngeal patterns were observed for the periodicity, rate, and degree of contraction. Pharyngeal movements for males during the second trimester were less rhythmic and characterized by incomplete contractions. In both trimesters, females demonstrated contraction periodicity of 85%, with pharyngeal contractions being complete 100% of the time (Miller). By the third trimester, the periodicity of pharyngeal contractions was similar across sexes; however, the percentage of complete pharyngeal contractions in male fetuses continued to be significantly lower (66%). Throughout the second trimester,
male laryngeal movements were less periodic (males 17%, females 55%) and incomplete. In the third trimester, laryngeal movements were similar across sexes. The decrease or plateau of prenatal female motor activity during the third trimester may be explained by possible early neurobehavioral development (Miller).

Few ultrasound studies have explored physical measurements of the upper digestive tract (Kalache et al., 1999; Tez et al., 2005; Richards & Farah, 1994; Wolfson & Laitman, 1990). The anatomical structure and function of the upper digestive tract may be a predictor in diagnosing ingestive dysfunction (Tez, 2005). However, Kalache et al. (1999) implies that upper airway dimensions are not a factor in diagnosing prenatal upper digestive tract obstructions. A cross-sectional study collected upper airway biometric measurements on 198 healthy fetuses (gestational age 15-40 weeks) and found a positive correlation between diameter and gestational age within the trachea, larynx, and pharynx (Kalache). At 15 weeks gestation, the mean laryngeal diameter was 4.08 mm and the mean pharyngeal diameter was 3.18 mm. By 40 weeks gestation, mean laryngeal diameter increased to 8.20 mm and pharyngeal diameter to 9.30 mm. Tez et al. (2005) also found a similar positive correlation between pharyngeal diameter and gestational age; the mean pharyngeal diameter was 4.5 mm at 16 weeks and 9.1 mm at 36 weeks gestation.

_Devvelopmental Feeding Skills_

Deglutition is a complex system that requires the coordination of more than 40 paired muscles, 6 cranial nerves, and 2 levels of the central nervous system, including the cerebral cortex and brainstem (Broniatowsk, 1999; Schindler & Kelly, 2002). From infancy to preschool age children, increasingly complex oral-motor functions become apparent with the maturation of the central nervous system and anatomical changes within the upper aerodigestive tract (Arvedson & Brodsky, 2002). Infants are well-equipped with primitive reflexes that contribute to the development of successful feeding skills. These primitive reflexes are activated by tactile input and allow the infant to sustain an oral diet (Dailey-Hall, 2001). During the first few months of life, the infant’s tongue fills the oral cavity and the width of the oral cavity is narrow due to fat pads located within the cheeks (Delaney & Arvedson). The larynx is also positioned superiorly, approximately anterior to C3-C4 of the spinal column, such that the epiglottis
comes in direct contact with the soft palate (Stemple, Glaze, & Klaben, 2000). This anatomical arrangement of oral structures is ideal for suckling, which is characterized by simple anterior-posterior tongue movements to extract nutrition during the first 6 months of life (Delaney & Arvedson, 2008). It was once believed that the superior anatomical position of the larynx allowed the infant to simultaneously breathe and swallow (Polgar & Weng, 1976). However, more recent research has confirmed that there is a cessation of respiration during both NNS and NS (Kelly, Huchabee, Jones, & Frampton, 2007).

At approximately 6 months of age, primitive reflexes diminish (i.e. transverse tongue reflex, tongue protrusion, rooting) and the infant begins to gain volitional control over tongue and jaw movements during mastication. During this time frame, the size of the oral cavity dramatically increases with the eruption of teeth and resorption of the sucking pads, allowing the child to tolerate and manipulate semisolids with more precise oral-motor movements (Arvedson & Brodsky, 2002). The infant will begin to progress from suckling to sucking behaviors, which is defined by increased tongue movements, reduced mandibular excursions, and a tight lip seal (Dailey-Hall, 2001).

Safe and successful oral feeding skills are dependent on the coordination and rhythm of the suck, swallow, and breathe triad (SSB) (Delaney & Arvedson, 2008). Previous research has suggested that NNS is a critical precursor to NS and determines the readiness for an oral diet (Delaney & Arvedson). However, more recent studies have disputed this claim because NNS does not require periodic swallowing as demonstrated in NS (Lau & Kusnierczyk, 2001). In addition, a study on healthy preterm infants found that using the NNS to teach the NS is not an efficient therapy (Pickler & Reyna, 2004; Scarborough, Miller, & Fletcher, 2008). It is acknowledged, that NNS in healthy preterm infants improves self-regulation, oxygen saturation levels, feeding performances, and gastric emptying (Scarborough et al., 2008). The infant’s behavioral state, cardiorespiratory regulation and rhythmic SSB patterns are important components in determining an infant’s readiness to sustain an oral diet. The expectation for an infant between 32-34 weeks is to maintain an oral diet necessary to meet their nutritional requirements (Delaney & Arvedson, 2008).

The 3 general approaches for describing sucking behaviors, include: 1) pressure changes within the nipple, 2) changes in intraoral pressure, and 3) changes in suction and
expression (Lau & Kusnierczyk, 2001). Previous studies have shown that expression can occur alone during NS; however, suction rarely occurs without the presence of expression (Lau & Kusnierczyk). This phenomenon suggests that rhythmic alteration between the suction and expression elements are not necessary for successful oral feeding. Lau, Alagugurusamy, Schanler, Smith, & Shulman (2000) have classified the development of NS during bottle feeding into five stages, ranging from low amplitude suction and arrhythmic expression to rhythmic suction and expression patterns similar to a full-term infant. As the infants progressed through the stages, the amplitude of expression did not change (range= 0.2-1 mmHG); however, the duration of the suction component (i.e. sucking bursts) increases with the maturation of oral motor skills (Lau et al., 2000). In addition, the rate of milk transfer increases as the infant’s progress through the stages. A study that investigated the influence of nipple position on successful breastfeeding in 18 mother-infant subjects (mean age 7-31 days), found the average rate of milk transfer for full-term infants to be 5 to 7 mL/min (Jacobs et al., 2007). Normal breastfeeding attachment is thought to be dependent on nipple to hard-soft palate distance (NHSPD) of zero; however, a recent pilot study has suggested that milk transfer is not associated with NHSPD. Jacobs et al. (2007) found that milk expression was observed upon compression of the nipple against the palate followed by a downward movement of the posterior tongue. However, tongue position during bottle feeding has been described differently in premature infants (Jacobs et al., 2007). Miller and Kang (2007) describe the tip of the tongue as being “anchored” in the anterior sulcus with the surface of the tongue demonstrating sequential peristaltic movements (Scarborough et al., 2008).

Between the ages of 2 to 4, the pharynx begins to elongate and widen, causing the descent of the tongue, larynx and hyoid bone. The descent of these anatomical structures is associated with developmental changes that will occur within the swallowing mechanism (Delaney & Arvedson, 2008). As the larynx lowers, the child will develop and master new respiration and swallowing patterns, including vital measures to protect their airway. To protect the airway, the larynx and hyoid bone are pulled upward and forward causing the epiglottis to depress and cover the laryngeal aditus. In addition, the aryepiglottic folds, false vocal folds, and true vocal folds adduct to close the larynx (Stemple et al., 2000).
By 3 years of age, a typically developing child will demonstrate consistent internal jaw stability when drinking from a cup and appropriate jaw grading for various food textures and thickness levels (Guerra & Vaugh, 1994). Jaw movements during mastication will be a mixture of up/down and circular rotary movements. The child will be able to transfer food from one side of the check to the other and will use the tongue to clean the teeth and sweep out food that goes into the lateral and anterior sulci. The child will be able to propel the bolus rapidly towards the oropharynx without anterior loss of the bolus due to adequate lip closure and tongue tip elevation during swallowing. During meal time, the child will also engage in turn-taking behaviors and parallel play.

As children become older their feeding behaviors mature, as characterized by increased oral motor control and precise movements of anatomical structures during feeding. Between the ages of 3 and 6, coordination of anatomical structures will become more mature during mastication as demonstrated by consistent circular rotary movements of the mandible (Kramer & Eicher, 1993). There is a significant gap in literature that reports specific feeding behaviors for a typically developing four year old child.

Sensorimotor Development

Sensory integration is a vital component during the feeding process and rapidly develops during the ages of 3 to 7 (Dailey-Hall, 2001). According to a study conducted by Gisel, Birnbaum, and Schwartz (1998), normal sensorimotor development is dependent on 4 essential requirements, including: 1) stability and mobility, 2) rhythmicity, 3) sensation, and 4) oral-motor efficiency and economy. The first requirement is dependent upon the interaction between stability and mobility. The infant needs to establish stability before mobility can be accomplished; stability first develops within the proximal body parts and gradually descends distally. For instance, stability of the oral mechanism is dependent upon its proximal counterpart, the neck and shoulder girdle. More specific, the stability of the mandible directly affects the fine motor movements or mobility of the tongue, lips, and cheeks (Morris & Klein, 1987).

Rhythm generators are common in the human body and are well-known within the circulatory, respiratory, swallowing, digestive, and sleep systems. The most consistent characteristic of a feeding pattern for an infant during the first three months of life is rhythm due to the suck-swallow-breath triad (Gewolb et al, 2001). Rythmicity of
the feeding mechanism begins in infancy and continues through childhood as the child encounters various textures of food. As the child makes the transition from one feeding pattern to another (i.e. bottle to the cup), the child must develop a new and mature rhythm (Morris & Klein, 1987).

Sensation is the third key factor for normal sensorimotor development. The olfactory and gustatory system work in unison to develop and enhance the sensory input necessary for bolus preparation. Research indicates that odors are frequently associated with the sense of taste in the oral cavity and highly relevant to food perception (Verhagen & Engelen, 2006). Sensory information from the oral cavity is received via mechanical, pain, proprioception, chemical, taste, smell, and temperature receptors. The sensory feedback that a child receives during feeding/swallowing is essential not only for the safety of the patient, but for the emotions associated with meal time (Rogers & Arvedson, 2005).

The final key requirement is oral motor efficiency and economy. During meal time, children will subconsciously choose the most efficient and economical oral-motor movements required to chew a specific food item. For instance, the child will not maintain adequate lip closure if they can compensate for anterior loss of the bolus through coordinated tongue, jaw, and cheek movements (Morris & Klein). Normal sensorimotor development will occur with the coexistence of these 4 essential factors.

Assessment of Pediatric Dysphagia

The anatomic structures and physiologic functions of the oral, pharyngeal, and laryngeal mechanisms are crucial for successful swallowing. When a deficit develops within one of these mechanisms, the result is dysphagia. Dysphagia is the impairment or inability to swallow, creating a disturbance for food in-take and/or movement of the bolus from the oral cavity to the esophagus (Dikeman & Kazandjian, 2003). Dysphagia may be characterized by severity ranging from mild to severe and location (oral, pharyngeal, or esophageal). The role of the speech-language pathologist is to assess dysphagia within the oral and pharyngeal phases of swallowing and execute appropriate dysphagia treatment (Dikeman & Kazandjian). A feeding and swallowing evaluation should integrate an interdisciplinary approach that involves a thorough medical and feeding history, oral motor examination, and clinical observation of feeding behaviors. Further
diagnostic testing may be involved to gain more information about the swallowing process and to aid in diagnosis (Josephson & Wohl, 2005).

Pediatric dysphagia can be an outcome of structural, physiological, and/or behavioral issues (Sonies, 1997). Many disorders can disrupt deglutition resulting in swallowing and feeding disorders. The major etiologies of pediatric dysphagia include: gastrointestinal tract disorders, respiratory disorders, central nervous system damage, peripheral nervous system damage, prematurity, structural abnormalities, and cardiac issues (Dailey-Hall, 2001). These etiologies can greatly impact the pharyngeal phase of swallowing and have long-lasting effects on the child’s health (Rogers & Arvedson, 2005). Through observation, the professional can assess the pharyngeal phase of swallowing by noting the following symptoms: 1) difficulty swallowing liquids/solids, 2) coughing, choking, or gagging during meal-time, 3) wet vocal quality following food presentation, 4) nasal regurgitation, 5) delayed trigger of the swallow, and 6) reduced hyolaryngeal elevation. However, to make an accurate diagnosis, instrumental assessment tools are often utilized to simultaneously observe the movement of anatomical structures and the bolus within the upper digestive tract.

**Instrumental Assessment Tools for Swallowing**

When assessing pediatric dysphagia the speech-language pathologist will utilize various methods to evaluate the swallowing mechanism. Common evaluation procedures include: fiberoptic endoscopic evaluation of swallowing (FEES), videofluoroscopic swallow study (VFSS), electromyography (EMG), pharyngeal manometry, scintigraphy, and ultrasonography (Dailey-Hall, 2001).

**Fiberoptic Endoscopic Evaluation of Swallowing**

During the FEES procedure, an endoscope is passed through the nasal cavity to the top of the pharynx. This superior view of the pharynx and surrounding structures occurs while the child swallows liquid and/or food of varying consistencies that contains dye. From this position, the professional can view the base of the tongue, pharynx, and the supraglottic larynx before and after the swallow (Suiter et al., 2009). FEES is a beneficial technique appropriate for all ages and can be performed in a radiology fluoroscopy suite or at bedside, where the child is positioned in his or her normal feeding position. Before presentation of food or liquid, the examiner places a small amount of
green dye on the child’s tongue. If the child aspirates oral secretions or is unable to trigger a swallow, the evaluation may be terminated (Arvedson & Brodsky, 2002). FEES does not expose the child to radiation; therefore, the procedure has no time constraints and may be repeated as necessary (Leder, 1991). In addition, aspiration can often be identified from the trace of dye residue; however, it is difficult to assess the degree of aspiration that occurs (Rubin, Broniatowski, & Kelly, 2000). Laryngeal sensation and sensory testing of the superior laryngeal nerve can be informally assessed by using the tip of the endoscope to touch specific areas within the hypolarynx and larynx and documenting the degree of reaction (Dailey-Hall, 2001). In addition, FEES can detect premature spilling of the bolus, vallecular and/or pyriform sinus residue, and laryngeal closure. FEES is recognized as a standard protocol for evaluating pediatric dysphagia with greater or equal sensitivity at detecting laryngeal penetration and determining diet recommendations when compared to VFSS (Leder & Karas, 2000; Suiter et al., 2009).

Flexible Endoscopic Evaluation of Swallowing with Sensory Testing (FEESST) may be performed in conjunction with the standard endoscope evaluation to obtain an objective measurement of laryngopharyngeal sensory thresholds (LPST). During FEESST, the endoscope is placed 5 mm above the aeryepiglottic fold and delivers a 50 millisecond air pulse to the arytenoid mucosa at a pressure ranging from 3 to 10 mm Hg. This procedure assesses the laryngeal adductor reflex (LAR) innervated through the superior laryngeal nerve by documenting the threshold that is required to elicit vocal fold closure (Willging & Thompson, 2005; Arvedson & Brodsky, 2002). Recent studies have found that a threshold less than 4 mm Hg is typically found in patients that do not exhibit aspiration. However, individuals with severe laryngeal penetration and/or aspiration demonstrate LPS thresholds above 10 mm Hg (Link, Willging, Miller, Cotton, & Rudolph, 2000; Liu, Kaplan, Parides, & Close, 2000). Within both adult and pediatric patients, there is a strong correlation between aspiration and increased LPST. Findings from FEES(ST) provide valuable information regarding the safety of oral feeding, especially for children with neurological impairments (Thompson, 2003). However, FEES(ST) is an invasive procedure that illustrates only partial examination of the pharyngeal phase and does not allow the professional to assess the oral or esophageal phases of swallowing (Arvedson & Brodsky, 2002). The amount of laryngeal pooling in
the hypopharynx complex may be used a substitute measure for laryngopharyngeal sensory testing (Willging & Thompson, 2005).

**Videofluoroscopic Swallow Study**

VFSS has been administered since the early 1980’s and is one of the most common instrumental assessment tools for evaluating the oral, pharyngeal, and upper-esophageal phases of swallowing. Prior to administration, the examiner should take into consideration the child’s positioning, amount and order of bolus presentation, and special adaptations that may need to be implemented for specific clinical situations. During VFSS, the child is fed liquid and/or food mixed with varying textures of barium (thin liquid to solid foods) via a bottle, cup or spoon (Morris & Klein, 2000). Caregivers are instructed to bring in samples of various foods within the child’s diet, especially food where the child has demonstrated signs or symptoms of dysphagia. Positioning during the VFSS is dependent of the child’s needs; however, optimal positioning entails adequate stability and central alignment. There are several pediatric equipment options that can be utilized during the procedure to obtain a desired position, including, an infant seat, tumbleform, cradle, Multiple Application Multiple Articulation (MAMA) seating system, and the McMullen Dysphagia chair (Arvedson & Brodsky, 2002). However, medical institutions may not have this equipment readily available for optimal positioning of patients. A VFSS study creates an unfamiliar feeding environment that may influence the child’s swallowing performance, therefore affecting the validity of the measurements obtained (Kuhl et al, 2003).

Following the trigger of a swallow, VFSS can provide valuable information about the timing and control of the bolus from the oral cavity to the esophagus. In addition, it can detect the amount of aspiration and determine the safest consistency for a patient (Morris & Klein, 1987). VFSS assesses all stages of deglutition in real time, where frame by frame analysis can be performed. However, there are a number of clinical situations, when VFSS is not appropriate and instead FEES becomes the preferred assessment. For instance, VFSS is not appropriate for pediatric patients that demonstrate a delayed to absent swallow reflex, inability to consume sufficient amounts of food or liquids, and/or a low tolerance for aspiration due to medical status (i.e. respiratory disorders). Another major limitation of this procedure is that the child is
exposed to radiation, which poses time constraints and may become a health concern if multiple reassessments are required (Kuhl et al., 2003). VFSS also requires the ingestion of barium contrast media and does not provide detailed information about the oral preparatory or oral transit stages of swallowing (Stolovitz & Gisel, 1991).

**Pharyngeal and Esophageal Manometry**

Pharyngeal manometry records and detects pressure activity within the pharynx. When the manometric sensor has direct contact with the pharyngeal wall, the device detects a measure of contact pressure. However, when the sensor is completely immersed in air or fluid the device collects a cavity pressure, also known as intrabolus pressure. Following a swallow, pharyngeal manometry detects the pressure changes that occur within the pharynx due to the contraction of the pharyngeal muscles, known as pharyngeal peristalsis (Baert & Sartor, 2004). Abnormal pressure measurements can be indicative of pharyngeal weakness. This technique is rarely implemented during the diagnostic process due to the rapid sequential movement of the pharyngeal structures and muscles, which results in inaccurate pressure recordings. However, solid-state manometric techniques with computerized analysis has lead to more accurate measurements (Baert & Sartor).

**Scintigraphy**

Pharyngeal and esophageal scintigraphy is an imaging technique that uses a radioactive material to assess the movement of the bolus from the oral cavity to the stomach. The radioisotope (Technetium Tc 99m) is mixed with liquid and/or soft food that is either ingested or presented to the child through a nasogastric (NG) tube (Dailey-Hall, 2001). Following presentation of the radioactive bolus, the child is scanned with a gamma camera for 1-2 hours to obtain measurements of bolus transit time, rate of gastric emptying, and the amount of material aspirated (Rubin, Broniatowski, & Kelly, 2000). Pharyngeal scintigraphy can indicate aspiration in the lungs; however, clinicians often find it difficult to conclude whether aspiration occurred during a reflux event or following the presentation of liquid/food (Miller, Larson, Saavedra, Scarborough, & Miller, 2008). Esophageal scintigraphy can detect gastrointestinal motility disorders and/or gastrointestinal reflux (GER). Reduced gastric emptying temporal measurements will yield a positive pH probe, which may indicate reflux (Arvedson & Brodsky, 2002).
Scintigraphy is more commonly used within the pediatric population due to limited exposure to radiation when compared to more common instrumental assessments, such as videofluoroscopy. Recent research, has also found scintigraphy to be a valuable diagnostic tool for adult patients with oropharyngeal dysphagia (Bogaardt, Burger, Fokkens, & Bennink, 2007). However, scintigraphy offers limited knowledge about the functioning of anatomic structures during deglutition since the procedure is performed post-meal. In addition, scintigraphy has low sensitivity and lacks standardization, thus this technique is often only used as a screening test (Arvedson & Brodsky, 2002).

**Electromyography**

EMG provides direct measures of laryngeal muscle activity relative to deglutition. Until recently, EMG has predominately been used as a research tool (Rubin et al., 2000). This invasive procedure is performed by a neurologist or otolaryngologist, who inserts needle electrodes into various laryngeal muscles. To verify accurate electrode placement, the patient performs various vocal tasks that require activation of specific laryngeal muscles. For instance, to confirm accurate placement within the cricothyroid muscle, the examiner could instruct the patient to produce a high frequency sound; the EMG recording should be active immediately following the high frequency production (Stemple, Glaze, & Klaben, 2000). The onset, timing, and amplitude patterns are analyzed during EMG recordings to detect pathological laryngeal muscle activity. EMG is most commonly used to diagnose vocal fold pathology, such as: paralysis, dystonia, and ankylosis. Results from an EMG recording frequently provides invaluable information regarding vocal fold closure and thus assesses airway protection of the patient during feeding. Electrodes may also be inserted into the pharyngeal muscles to obtain further information about pharyngeal muscle activity. However, electrodes are difficult to insert into the pharyngeal muscles because these muscles are relatively thin and move during deglutition; therefore, increasing the likelihood of electrode displacement (Rubin et al., 2000). EMG also does not provide a visual representation in regards to muscle movement and bolus transition and is not capable of detecting aspiration.
**Ultrasonography**

Ultrasonography captures images and displays the movement of anatomic structures, muscles, and tissues (Bressman et al., 2005; Lefton-Greif & Laughlin, 1996). The ultrasound transducer contains a piezoelectric crystal that first generates a pulse of high frequency sound waves that are transmitted through the skin and underlying structures. During diagnostic imaging, the frequencies of sound waves are not audible by the human ear and range between 2 and 10 MHz (Arvedson & Brodsky, 2002). The transducer then switches into a receiving mode where it collects the reflected echoes; it repeats this process several hundred times a second to generate a precise 2 dimensional image in real-time (Bressmann et al., 2005; Yang et al., 1997). The sound waves from the transducer vibrate internal structures at various intensities reflecting echoes; this occurrence is dependent upon the density of the structure and is portrayed on the ultrasound screen as various shades of gray, ranging from black to white (Lefton-Greif & Laughlin, 1996). Soft tissue, muscles, and glands will appear as a lighter shade of gray compared to a more dense anatomic structure, such as the hyoid bone (Arvedson & Brodsky, 2002).

For a number of years, ultrasound has been used as phonetic research tool to analyze tongue placement for individual speech sounds (Morrish, Stone, Sonies, Kurtz, & Shawker, 1984; Shawker & Sonies, 1984; Vazquez-Alvarez & Hewlett, 2007). Although, the majority of ultrasound research has focused on the oral and pharyngeal phases of swallowing within the adult population (Casas et al., 2003; Chi-Fishman et al., 1998; Chi-Fishman & Sonies, 2002; Frattali et al., 1999; Kuhl et al., 2003; Miller & Watkin, 1997; Peng, et al., 2000; Shawker et al., 1983; Shawker et al., 1984; Soder & Miller, 2002; Sonies et al., 1988) and suckling behaviors in infants (Bosma et al., 1990; Bu’Lock et al., 1990; Jacobs et al., 2007; Miller & Kang, 2007; Smith et al., 1985; Weber et al., 1986). In addition, ultrasound has been established as a valuable biofeedback tool for individuals with hearing loss (Bernhardt, Gick, Bacsfalvi, & Ashdown, 2003) and articulation errors (Modhah, Bernhardt, Church, & Bacsfalvi, 2008; Shawker & Sonies, 1985).

The continuous advancements in computer technology and the growing competition among manufacturing companies have led to affordable prices. This
phenomenon has allowed a number of medical institutions and researchers within the field of speech-language pathology to purchase ultrasound machines. In recent years, ultrasound has been utilized as an instrumental tool to assess swallowing patterns and to diagnose and treat those with swallowing disorders (Bressman et al., 2005). The procedure is most beneficial when assessing the oral preparatory and oral transit stages of swallowing (Casas, Seo, & Kenny, 2002). However, ultrasound also provides valuable information regarding vallecular stasis and abnormal laryngeal and hyoid bone movement (Rubin et al., 2000). The hyoid can be viewed using ultrasound in the two planes of reference during an ultrasonic procedure: mid-sagittal and coronal. Mid-sagittal allows anatomic viewing of the hyoid shadow, where the total movement of the hyoid can be measured in centimeters. The coronal placement of the probe in conjunction with a specialized ultrasound setting can provide discrete temporal measurements (Chi-Fishman & Sonies, 2002).

Ultrasound is free from ionizing radiation (i.e. x-ray) and may be portable for the use in a home or clinic setting (Bressman et al., 2005). Ultrasound is an objective tool that has no time constraints and allows for multiple examinations to evaluate treatment efficacy (Casas et al., 2002). During an ultrasonic procedure, the equipment supports a natural feeding position and the examiner administers real food (without contrast media) to elicit swallows (Casas et al., 2002; Yang et al., 1997; Lefton-Greif & Loughlin, 1996). The examiner can use frame by frame analysis to obtain detailed measurements and the entire procedure may be recorded for later viewing (Bressman et al., 2005).

The accuracy of measurements obtained during an ultrasonic procedure may become a concern if the child does not maintain appropriate head fixation or if the examiners hand moves during the procedure, therefore changing the angle of the transducer (Bressman et al., 2005). Ultrasound allows for the viewing of liquid consistencies without contrast media; however, the visualization of some liquids is unclear due to similar densities or acoustic characteristics of surrounding anatomical structures (Casas et al., 2002). Casas et al. (2002) investigated bolus image enhancement and found that cola results in improved sonographic visualization of swallowing when compared to water. Ultrasound provides detailed information about the oral phases of swallowing; however, it fails to detect aspiration and provides limited explanations for
the presence of dysphagia or aspiration (Lefton-Greif & Loughlin, 1996). Therefore, when assessing a child at-risk for aspiration (i.e. neurological impairments) it is important to utilize ultrasound as a supplemental tool to FEES or VFSS (Arvedson et al., 1994).

**Statement and Significance of the Problem**

Despite the vast amount of research dedicated to ultrasonography and the swallowing mechanism, no published data exists on preschool age children; thus, this gap in the literature necessitates further research. Ultrasonography provides a means of evaluating pediatric swallowing patterns without exposure to harmful radiation and unnatural feeding environments that may negatively influence results and feeding recommendations. Utilizing ultrasound as an objective diagnostic tool to establish normative parameters for hyoid bone displacement in preschool-aged children will assist in the safe and accurate diagnoses of pediatric dysphagia.

**Purpose of the Study**

The purpose of this study is to establish normative parameters regarding the total distance of hyoid bone displacement following discrete bolus sizes of puree and liquid in typically developing three and four year old children. The study will also attempt to determine any influential factors on hyoid bone displacement, such as, gender and age.

**Hypotheses**

1. Typically developing 3 to 4 year old children will display a wide variability in hyoid bone displacement following discrete bolus sizes of liquid and puree.
2. Consistency of the bolus will be influential factor on hyoid bone displacement in 3 and 4 year old children.
3. Bolus size will be an influential factor on hyoid bone displacement in 3 and 4 year old children.
4. There will be an interaction effect between bolus size and consistency on hyoid bone displacement for liquid and puree consistencies in typically developing 3 and 4 year old children.
5. Chronological age will not be an influential factor in hyoid bone displacement following presentation of discrete bolus sizes of liquid and puree.
6. Following discrete bolus size of liquid and puree, typically developing 3 and 4 children will not demonstrate a significant gender effect.
CHAPTER III
Methods and Procedures

Recruitment and Selection of Subjects

The methods and procedures utilized in this study were reviewed and approved by the Institutional Review Board for Human Subjects Research (IRB) for Miami University. A priori tolerance interval was used to determine the number of subjects necessary to create a statistically significant research study; this was determined to be a minimum of 20 subjects. Subjects were recruited from five preschools within the Greater Cincinnati area. The recruited preschools were located in a wide range of socioeconomic regions within Southwest Ohio. Subjects were excluded from the study based on the following criteria: 1) younger than 36 months or older than 48 months of age 2) absence of age appropriate gross motor skills or cognitive functioning, and 3) a significant medical history that may influence their ability to swallow. From a feeding perspective, the children were required to be able to eat upright in a chair, feed from a spoon, and had volitional control of the muscles within the oral cavity.

A verbal description of the research study was provided to preschool directors via telephone. Prior to initiating the study, both verbal and written consent was obtained by the preschool directors from their respective institutions to participate in the study. The researchers then either hand-delivered or mailed the following material to be distributed to the parents/legal guardians that had children who met the age requirement: a recruitment flyer, introductory letter, and questionnaire (see Appendix A, B, C). The introductory letter served to inform the parents about the details of the study and to obtain informed consent from the parents/legal guardians. This document was written at a reduced reading level and jargon was eliminated. An informed consent was signed by the child’s parents/legal guardians and returned to the preschool director (see Appendix B). The preschool director then contacted the researchers to set-up an appointment for any parent interested in the study. Recruiting families and their children for research purposes can potentially be challenging, particularly with typically developing children. As an incentive to recruit families, each child that participated in the research study received a $25 gift card to Kroger (i.e. retail food chain). In addition, the parental questionnaire served as a screening procedure to determine participant eligibility.
Participation of the study was not required and a child was able to refuse participation at any time during the procedure.

Research Procedures/Methods

Each study took place at the child’s preschool and contained three parts, including: 1) questionnaire, 2) oral motor screening, and an 3) ultrasonic procedure. The purpose of the questionnaire was to collect information on the child’s health and development to ensure inclusion criterion was met. In addition, the questionnaire served to rule out possible food allergies and to obtain their preference of food (i.e. pudding or applesauce) to be utilized during the ultrasonic portion of the study. The questionnaire was sent home with the child’s parents/legal guardians and returned to the preschool director with the informed consent. Parents were also provided contact information of the investigators if any questions arose during the study. The questionnaire took approximately 5-10 minutes to complete.

During the second part of the study, subjects underwent a brief oral motor screening that was utilized as part of standard clinical evaluation to verify that subjects were within developmental normative parameters. The oral motor screening involved the visual inspection of the structures and muscles within the oral cavity and their symmetry, strength, range of motion, and coordination. The oral motor screening took less than 5 minutes to complete.

Finally, subjects participated in an ultrasonic procedure where information was collected using a portable Aloka 900 SSD with a pediatric probe (type UST 987-7.5 MHz, 65 degree, 20 mm radius). Since the initial use of diagnostic ultrasound, human biological effects from ultrasound exposure have been studied by various scientific and medical institutions. For the level and type of diagnostic ultrasound used in this study, there are no known harmful effects (Ziskin & Petitti, 1988). All diagnostic equipment operated within FDA guidelines. The probe depth was placed at 5 cm in order to obtain a more detailed view of the hyoid bone and posterior tongue (Frattali, et al., 1999).

A team of students and a faculty researcher completed this study. The graduate and undergraduate students underwent a 9 month training program by Aloka representatives and Dr. Donna Scarborough (Miami University- Oxford) regarding the probe placement and proper procedures; the researchers met weekly for 30-45 minute
sessions. For each ultrasonic procedure at least 3 examiners were present, each with a specific role regarding data collection. One researcher administered the bolus to the child while another researcher measured hyoid bone displacement. To reduce head movement during swallows, the researcher in charge of administering the bolus would wear a sticker on their chin and the child was asked to watch the sticker as they swallowed. Occasionally, a descriptive verbal cue was given to reduce head and body movement (i.e. sit like a statue). A third researcher was responsible for pre-measuring bolus sizes, recording measurements on designated data collection sheets, assisting in proper head position, and regulating the child’s behavior. At times, the researcher would provide gentle head support as a cue to maintain head position by carefully placing 2 hands at the side of the child’s head. Swallows were repeated if head movement interfered with data collection. Between swallows, if the child was demonstrating fatigue or low levels of interest, the child would be engaged in a short physical activity, such as: blowing bubbles, jumping, and/or playing with a toy.

For this study, the probe was placed in the mid-sagittal plane of reference for anatomic viewing of the tongue base and hyoid bone shadow. The total movement of the hyoid bone was obtained for each swallow following discrete bolus sizes of puree and liquid presented via spoons. The researchers consistently measured hyoid bone movement from a specific line of reference along the y-axis of the ultrasound screen to ensure consistency across researchers. Following the capture of a swallow, frame-by-frame analysis was performed to identify and mark the resting position and maximum displacement point of the hyoid bone using an internal function of the ultrasound device. The ultrasound machine also has a mechanism that allows for temporary storage and identification of a starting point (slide 1) and ending point (slide 25) following hyoid bone displacement. Measurements of hyoid bone displacement were immediately obtained following a swallow due to limited storage memory and inability to manipulate and apply measurement functions for later use. Total hyoid bone movement was obtained by drawing a continuous horizontal line from the resting position to the point of maximum displacement along the fourth line of the y-axis where the image of the hyoid bone shadow is consistent and visually enhanced.
For each subject, room temperature water was utilized as a liquid consistency while puree consistency entailed either pudding or applesauce. The following three bolus sizes were administered: .5cc, 1.5cc, and 2.5 cc. For both puree and liquid consistencies, two measurements were obtained at each bolus size. All boluses were pre-measured using 1 and 3 cc syringes before placed on a standard white plastic spoon (tsp) for presentation. Subjects were seated upright in a chair and swallows were spontaneously captured; verbal cueing was not provided. Randomization procedures were implemented within the study to increase internal validity. Task order was randomized for the presentation of liquid and puree and the presentation of discreet bolus sizes. The ultrasound portion of the study took approximately 20-30 minutes to complete, variation was dependent on individual subjects and cooperation.

**Hypotheses and Research Questions**

The study integrated both descriptive and statistical analysis for the collection, analysis, and interpretation of the data.

**Descriptive Analysis of Data**

Descriptive analysis was implemented in the study to summarize and draw inferences from the collection of data. Descriptive data included, mean hyoid bone displacement (cm), standard deviation, minimum/maximum, and range.

**Descriptive Research Hypothesis and Questions**

Hypothesis 1: Typically developing 3 and 4 year old children will display a wide variability in hyoid bone displacement following discrete bolus size (.5 cc, 1.5 cc, 2.5 cc) of liquid and puree. The following descriptive research questions will address the preceding hypothesis:

1. What are normative parameters for hyoid bone displacement following 0.5 cc of liquid and puree for 3 and 4 year old children?
2. What are normative parameters for hyoid bone displacement following 1.5 cc of liquid and puree for 3 and 4 year old children.
3. What are normative parameters for hyoid bone displacement following 2.5 cc of liquid and puree for 3 and 4 year old children?
**Statistical Analysis of Data**

Data was analyzed using a repeated-measures mixed model analysis of variance with SAS windows version 9.1 to investigate the effects of consistency, volume, age, and gender on hyoid bone displacement. The research design was implemented due to the multiple dependent variables under investigation as detailed in each of the following research questions.

**Statistical Hypotheses**

Hypothesis 2: Consistency of the bolus will be influential factor on hyoid bone displacement in 3 and 4 year old children.

Hypothesis 3: Bolus size will be an influential factor on hyoid bone displacement in 3 and 4 year old children.

Hypothesis 4: There will be an interaction effect between bolus size and consistency on hyoid bone displacement for liquid and puree consistencies in typically developing 3 and 4 year old children.

Hypothesis 5: Chronological age will not be an influential factor in hyoid bone displacement following presentation of discrete bolus sizes of liquid and puree.

Hypothesis 6: Following discrete bolus size of liquid and puree, typically developing 3 and 4 year old children will not demonstrate a significant gender effect.

**Statistical Research Questions and Hypothesis**

The following statistical research questions were posed:

4. Is there an interaction effect between consistency and hyoid bone displacement?
   As stated in hypothesis 2, it is expected that the consistency of the bolus will be influential factor on hyoid bone displacement in 3 and 4 year old children.

5. Is there an interaction effect between bolus size and hyoid bone displacement?
   As stated in hypothesis 3, it is anticipated that bolus size will be an influential factor on hyoid bone displacement in 3 and 4 year old children.

6. Is there an interaction effect between consistency and bolus size on hyoid bone displacement?
   As stated in hypothesis 4, it is predicted that there will be an interaction effect between bolus size and consistency on hyoid bone displacement for liquid and puree consistencies in typically developing 3 and 4 year old children.
7. Is there an interaction effect between age and hyoid bone displacement?
   As stated in hypothesis 5, it is anticipated that chronological age will not be an
   influential factor in hyoid bone displacement following presentation of discrete
   bolus sizes of liquid and puree

8. Is there an interaction effect between gender and hyoid bone displacement?
   As stated in hypothesis 6, it is predicted that typically developing 3 and 4 year old
   children will not demonstrate a significant gender effect.
Chapter IV

Results

For this study, a total of 29 subjects were recruited between 3 and 4 years of age, which included 16 males and 13 females. The average age of the participants was 4:2 years (range 3:0-4:10 years). An additional 2 subjects were recruited; however, both subjects refused to participate during the ultrasonic portion of the study.

Research Question 1: What are normative parameters for hyoid bone displacement following 0.5 cc of liquid and puree for 3 and 4 year old children?

In male subjects, a mean hyoid bone displacement of 1.28 cm (SD=0.46) was observed for 0.5 cc of liquid with a normative range of 0.52-2.62 cm. For 0.5 cc of puree, the mean hyoid bone displacement was 1.21 cm (SD=0.26) with a normative range of 0.70-2.03 cm (See Figure 1; Figure 4; Figure 5).

For female subjects, measurements taken for a bolus size of 0.5 cc of liquid revealed a mean measurement of 1.59 cm (SD=0.33) with a normative range of 0.66-2.74 cm. Mean measurements for a bolus size of 0.5 cc of puree demonstrated a mean hyoid bone displacement of 1.30 cm (SD=0.39) with a normative range of 0.66-2.32 cm (See Figure 1; Figure 4; Figure 5).

Figure 1.
Mean Hyoid Bone Displacement for Males and Females at .5 cc of Liquid and Puree
Research Question 2: What are normative parameters for hyoid bone displacement following 1.5 cc of liquid and puree for 3 and 4 year old children?

For male subjects, a mean hyoid bone displacement of 1.28 cm (SD=0.20) was observed for 1.5 cc of liquid with a range of 0.88-1.95 cm. A bolus size of 1.5 cc of puree demonstrated a mean measurement of 1.32 cm (SD=0.32) with a normative range of 0.52-2.19 cm (See Figure 2; Figure 4; Figure 5).

In female subjects, a bolus size of 1.5 cc of liquid revealed a mean measurement of 1.45 cm (SD=0.32) with a normal range of 0.88-2.62 cm. For 1.5 cc of puree, the mean hyoid bone displacement measurement was 1.52 cm (SD=0.23) with a normative range of 0.95-2.09 cm (See Figure 2; Figure 4; Figure 5).

Figure 2.
Mean Hyoid Bone Displacement for Males and Females at 1.5 cc of Liquid and Puree

Research Question 3: What are normative parameters for hyoid bone displacement following 2.5 cc of liquid and puree for 3 and 4 year old children.

In male subjects, a mean hyoid bone displacement of 1.33 cm (SD=0.46) was observed for 2.5 cc of liquid with a normative range of 0.47-2.44 cm. For 2.5 cc of
puree, the mean measurement was 1.28 cm (SD=0.34) with a normative range of 0.58-2.38 cm (See Figure 3; Figure 4; Figure 5).

For female subjects, measurements taken for a bolus size of 2.5 cc of liquid revealed a mean measurement of 1.47 cm (SD=0.33) with a normative range of 0.64-2.11 cm. Mean hyoid bone displacement for a bolus size of 2.5 cc of puree demonstrated a mean measurement of 1.52 cm (SD=.39) with a normative range of 0.77-2.42 cm (See Figure 3; Figure 4; Figure 5).

**Figure 3.**
Mean Hyoid Bone Displacement for Males and Females at 2.5cc of Liquid and Puree

<table>
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Figure 4.
Mean, Standard Deviation, and Maximum and Minimum Hyoid Bone Movement at .5 cc, 1.5 cc, and 2.5 cc for Liquid and Puree Consistencies in Male Subjects

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Figure 5.
Mean, Standard Deviation, and Maximum and Minimum Hyoid Bone Movement at .5 cc, 1.5 cc, and 2.5 cc for Liquid and Puree Consistencies in Female Subjects

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<th>Consistency</th>
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Research Question 4: Is there an interaction effect between consistency and hyoid bone displacement?

The study investigated two consistencies (liquid and puree) and its effects on hyoid bone displacement. Subjects were given the choice of either pudding or applesauce for the puree consistency while room temperature water was used for the liquid consistency. The majority of subjects (n=19) requested pudding during the ultrasonic portion of the study. There was no interaction effect found between consistency and hyoid bone displacement (p-value=0.28).

Research Question 5: Is there an interaction effect between bolus size and hyoid bone displacement?

The following three bolus sizes were investigated: 0.5cc, 1.5cc, and 2.5 cc. The study revealed no interaction effect found between bolus size and hyoid bone displacement (p-value=0.48).

Research Question 6: Is there an interaction effect between consistency and bolus size on hyoid bone displacement?

The results revealed a marginally significant interaction effect between consistency and bolus size regardless of age or gender differences (p-value=.078). Therefore, the effect of bolus size on hyoid bone displacement is dependent on the consistency. When further analyzed at specific bolus sizes, there was a significant difference due to consistency at 0.5 cc (p-value=0.017). Mean hyoid bone displacement was significantly higher at 0.5 cc of liquid (mean= 1.434, SE= 0.064) than at 0.5 cc of puree (mean=1.261, SE=0.064). There was not an interaction effect between consistency and bolus size on hyoid bone displacement at 1.5 cc (p-value=0.46) or 2.5 cc (p-value=0.91). Figure 6 shows the interaction effect between consistency and bolus size on hyoid bone movement at 0.5 cc, 1.5 cc, and 2.5 cc.
Research Question 7: Is there an interaction effect between age and hyoid bone displacement?

The study consisted of preschool age children, approximately 3 and 4 years old. Specifically, our sample included a mean age of 4:2 years, ranging from 3:0 to 4:10. The sample included approximately 9 subjects that were 3 years old and 20 subjects of age 4. Regardless of unequal groups the study demonstrated no effect due to age (p-value=0.33).

Research Question 8: Is there an interaction effect between gender and hyoid bone displacement?

A significant gender effect was observed across all consistencies and bolus sizes (p-value=0.04). Mean hyoid bone movement was significantly higher in females (mean=1.4815, SE = 1.167) than in males (mean=1.2849, SE=0.061) (See Figure 7).
Figure 7.
Gender Effect on Hyoid Bone Displacement
Chapter V

Discussion

This is the first study that has successfully established preliminary normative data on hyoid bone displacement within a preschool population. The methodological approach employed to obtain this data was designed to answer a series of research questions.

Results revealed small variability in hyoid bone displacement; therefore, the data refutes the first hypothesis and indicates only slight individual variances between children. The overall standard deviation of hyoid bone displacement within our sample of preschool aged children ranged from 0.23-0.46 cm. When further investigated, standard deviation for female subjects across all consistencies (thin and puree) and volumes (0.5 cc, 1.5 cc, 2.5 cc) ranged from 0.23-0.33 cm. Similar, male subjects demonstrated a standard deviation ranging from 0.26-0.46 cm. This variability is relatively consistent with data obtained for adults (Ishida et al., 2002; Chi-Fishman et. al, 2002). However, it is difficult to compare data due to the varying volume sizes and consistencies under investigation. Chi Fishman, et al. (2002) conducted a study on 31 healthy adults (age 20-79 years); the study reported a standard deviation of 0.89 for male subjects and 1.26 cm for female subjects across all across consistencies (thin, nectar-like, honey-like, and spoon-thick) and volumes (5 cc, 10 cc, 20 cc, and 30 cc). Ishida (2002) conducted a study with 12 healthy adults (age 20-28 years) and reported a standard deviation of 2.7 mm (0.27cm) for male subjects following 8 g of a solid consistency compared to a standard deviation of 2.5 mm (0.25 cm) for female subjects. Standard deviation for 8 cc of a liquid consistency (barium-water mixture) for male participants was 3.0 mm (0.30 cm) and 3.8 mm (0.38 cm) for female subjects. The slight variances in hyoid bone displacement may be a result of anatomical differences (i.e. size of oral cavity, distance between mandible and hyoid bone, etc) and individual variances in eating habits. For instance, some subjects would engage in bolus preparation for longer periods, tongue pumping, reduced mandible excursions, and/or double swallows to clear the bolus from the oral cavity.

Our results found no significant interaction effect on consistency and hyoid bone displacement; this data refutes the second hypothesis. Within adult literature, studies
have reported that thicker consistencies produced greater hyoid displacement (Chi-Fishman & Sonies, 2002; Dantas & Dodds, 1990; Dantas, Dodds, Massey, & Kern, 1989). In contrast, other studies have found no significant effects between consistency and hyoid bone displacement (Ishida, et al., 2002; Kendall et al., 2001; Perlman, Vandaele, & Otterbacher, 1995). The variability in research findings may be attributed to methodological differences between studies. For instance, a wide range of diagnostic tools (i.e. ultrasonography, videofluoroscopy, scintigraphy, etc) have been implemented as well as subjectively measured viscosities (Chi-Fishman & Sonies, 2002).

Three bolus sizes were investigated in our study, including: 0.5 cc, 1.5 cc, and 2.5 cc. The data revealed no significant interaction effect between bolus size and hyoid bone displacement. Thus, this finding refutes the third hypothesis. Bolus size may not have an influential factor due to the close proximity between volume sizes. Within adult literature, many studies have reported that greater volumes induce greater hyoid bone displacements (Chi-Fishman et al., 2002; Jacob et al., 1989; Kendall et al., 1989; Logemann et al., 2000; Leonard et. al, 2000). In contrast, one study found no significant effect on hyoid bone displacement in regards to bolus size (Wintzen, et al., 1994). The previously stated adult studies investigate a greater range of volumes and thereby offer a reasonable explanation for our findings.

Our data did show a marginally significant interaction effect between consistency and bolus size on hyoid bone movement (p-value = 0.078), especially between .5 cc of liquid and puree (p-value = 0.017) which supports the fourth hypothesis. The mean hyoid bone movement at 0.5 cc of liquid (mean = 1.4347) was significantly higher than the mean hyoid bone movement at 0.5cc of puree (mean = 1.2619). This phenomenon suggests that a strong correlation between consistency and a bolus size of 0.5 cc on hyoid bone displacement; however, as the amount increased (1.5 and 2.5 cc), the interaction between consistency and bolus size became less relevant.

The strong correlation between consistency and bolus size at 0.5 cc may be explained by a study that investigated the influence of bolus consistency (water, applesauce, and pudding) and volume (5, 10, and 20 ml) on anterior lingual movements in adults. The results indicated a significant increase in lingual force amplitude as consistency increased; however, the volume did not have a significant effect on lingual
force (Miller & Watkin, 1996). The mean hyoid bone displacement for puree may be lower because of the high lingual force propelling the bolus towards the nasopharynx. The generation of increased pharyngeal pressure during puree consistencies may reduce the amount of pharyngeal and laryngeal movements necessary for safe swallowing. Puree consistency also requires increased bolus preparation time; thus, increased recruitment of bolus formation muscles and intrinsic laryngeal muscles that elevate and depress the hyoid bone. The recruitment of various muscular forces with thicker consistencies may reduce the need for hyoid bone displacement. Another study found a strong correlation between jaw and tongue movements during solid consistencies on hyoid bone excursion (Soder et al., 2002). Maximum elevation of the hyoid bone is achieved when the tongue is elevated and the upper and lower jaws are in close proximity. Whereas, maximal downward displacement of the hyoid bone occurs when the tongue is against the floor of the mouth and the mandible and maxilla are separated (Soder et al., 2002). All subjects in the study demonstrated increased effort during bolus formation for puree consistencies where tongue pumping and jaw excursions were present. Hyoid bone displacement may be less during puree versus liquid consistencies if the hyoid bone is elevated prior to a swallow. However, our findings showed no interaction effect between consistency and bolus size on hyoid bone displacement at 1.5 cc and 2.5 cc; therefore, this series of findings in the literature do not fully explain the interaction that we reported.

Support for hypothesis 4 by our data may instead be explained by the interaction between oropharyngeal events during deglutition and sensorimotor input. Studies have shown that the bolus transit time is faster for liquids than for thicker consistencies (Kendall, Leonard, McKenzie, 2001). It is also well recognized that liquid consistencies receive less sensory input from the swallowing mechanism. Due to the lack of sensory input and rapid temporal effects the hyoid bone is pulled in a greater upward-forward motion to protect the individual from aspiration. Hyoid bone displacement may also be greater due to the integration of precise muscle movements to manage a small bolus. Therefore, because we used a 0.5 cc liquid bolus, the swallowing patterns observed would be similar to a dry swallow, thus demonstrating greater hyoid bone movement.
The results of this study demonstrated no effect due to age (p-value=0.33); therefore supporting the fifth hypothesis. The sample population included a mean age of 4:2 years, ranging from 3:0 to 4:10. This finding is most likely contributed to the confined age range under study. Within the adult population, chronological age has demonstrated a significant effect on hyoid bone displacement and temporal movements of the hyolaryngeal complex (Medell et al., 2007; Chi-Fishman et al., 2002; Ishida et al. 2002; Sonies et al., 1988). For instance, with age the pharyngeal swallow is triggered further back in the oropharynx (i.e. ramus of the mandible) and there is decreased laryngeal elevation and delayed initiation of maximum hyoid bone displacement. Due to decreased hyolaryngeal elevation, the onset of the UES is also delayed and the duration of apnea during deglutition is extended (Medell & Logemann, 2007).

In hypothesis 6, we did not anticipate a gender difference due to the similarity between anatomical structures in the hyolaryngeal complex. The specific age range under study (3 and 4 year olds) should have similar anatomical structures relative to deglutition prior to mid-facial growth that occurs near age 6 or the descent of the hyoid bone in males during adolescence. Although we did find a gender difference the findings were not what we expected. Mean hyoid bone movement was significantly higher in females (mean= 1.4815, SE = 1.167) than in males (mean=1.2849, SE=0.061). In adults, males tend to display a greater hyoid bone excursion due to the lower resting position of the hyoid bone which descends during puberty (Ishida et al., 2002). A difference for males is a logical finding in adults; however, it does not explain the phenomenon that our results revealed. Gender differences have been reported in ultrasound studies involving fetuses. Female fetuses have demonstrated more mature and complex pharyngeal patterns via ultrasound (Miller et al., 2006). Therefore, one plausible explanation is this gender-specific phenomenon may have an affect on post-natal motor skills across gender for the first few year of life. Between the ages of 2 to 4, the pharynx begins to elongate and widen, causing the descent of the tongue, larynx and hyoid bone (Delaney & Arvedson, 2008). Therefore, greater hyoid bone displacement within the female population may be explained by early anatomical and maturational effects. This interesting finding may also be contributed to early nursing, sucking, and feeding behaviors. Our procedures included a brief questionnaire (Appendix C) that was
distributed to parents/legal guardians as a screening to exclude children with an extensive medical history that may influence their ability to swallow and those without age appropriate gross motor skills. Future studies may attempt to explain greater hyoid bone displacement in females through an extensive questionnaire that targets the developmental history of each subject in regards to maturational feeding skills and gross/fine motor abilities. Perhaps the male subjects in our study demonstrated immature feeding behaviors, gross motor skills, and/or fine motor skills during the first few years of their life; therefore, demonstrating less hyoid bone displacement at 3 and 4 years of age.

Summary and Limitations

The present study was successful in establishing preliminary normative parameters regarding the total distance of hyoid bone displacement following discrete bolus sizes of puree (pudding or applesauce) and liquid (room temperature water) in typically developing 3 and 4 year old children. A priori tolerance interval was used to determine the number of subjects necessary to create a statistically significant research study (n=20), the researchers were able to successfully recruit and collect data on 29 preschool aged children. However, this preliminary study facilitates the need for future research with more statistical power to validate the marginally significant interaction effect between bolus size and consistency on hyoid bone displacement and to increase the reliability of the proposed normative parameters. The study was successful in integrating subjects from across a number of socioeconomic classes and from multiple facilities; however, the researchers were limited to a particular geographic region (Southwest Ohio). The researchers acknowledge that this will reduce the ability to generalize the results to the studied population. The researchers followed strict methods that implemented randomization procedures for the presentation of liquid and puree consistencies, presentation of discrete bolus sizes, and task order for examiners. However, randomization procedures were not followed for the recruitment of subjects due to the restricted geographic region for recruitment.

Future Research

The preliminary study compels further studies within this research parameter to establish accurate parameters for hyoid bone displacement in typically developing 3 and 4 year old children. Although the sample size met the requirements for a preliminary
study, there is a need for a larger and more diverse sample size to increase the external validity of the results. Subjects should be recruited from numerous facilities within a greater geographic region. To ensure accuracy of hyoid bone displacement measurements, future studies should continue to use objectively measured volumes and consistencies.
References


Language Pathology and Audiology, 29(4), 158-168.


Appendix A: Recruitment Flyer

We need healthy kids!!!!!!!

➢ Is your child healthy overall?
➢ Is your child between 36 and 60 months old?
➢ You can help!!!!!!!

Hello, my name is Susan Waizenhofer. I am a graduate student in Speech Pathology and Audiology at Miami University. I am working on a project that looks at healthy children while they swallow. The swallow will be recorded while using an ultrasound machine.

Important details:

1. The study has three parts that will occur in one 30-40 minute session:
   a questionnaire, a brief oral motor screening and use of ultrasound
   (placed under the chin) during a small snack.
2. The study will take place at your child’s preschool.
3. The parent will have to fill out a consent form to participate.
4. The family would be reimbursed with a $25.00 Kroger gift card.
5. All information about your child will be confidential and HIPPA regulations will be used to protect your child’s information.

Thank you for your time!
Susan Waizenhofer, BS, Graduate Clinician
Phone: (513)-260-8138
Email: waizensl@muohio.edu
Miami University- Speech Language Pathology Department
Leah Siekemeyer, Undergraduate Researcher
siekemlc@muohio.edu

Brianna Kellems, Undergraduate Researcher
kellembc@muohio.edu
Appendix B: Participation and Informed Consent

Dear Parent:

Hello, I would like to introduce a team of students from the department of Speech Language Pathology at Miami University.

You and your child are invited to participate in a study that will look at swallowing in 3-4 year old children. You (parent/guardian) will be asked to complete a short survey about your child’s health. If your child is healthy then your child will be asked to: 1) have our team look in their mouth and, 2) have an ultrasound on their neck while they swallow.

Things to know:

- Your child will have the study done at school and the study only takes about 20 minutes.
- Ultrasound is safe, not painful, and does not use radiation.
- Your child will be given small amounts of food and liquid while the ultrasound camera is placed under their chin. Gel will be put on the camera before each picture is taken. This gel easily wipes off and will not stain clothes.
- This study will help us understand more about swallowing and how ultrasound may benefit children with feeding difficulties.
- Information from the survey and study will be kept confidential.
- You may decide to remove your child from the study at any time or refuse to answer any questions that make you uncomfortable.

Thank you from the Miami University Ultrasound Team!

If you have any additional questions about the study, please contact:

Susan Waizenhofer, Graduate Team Leader
phone number: (513)-260-8138 e-mail: waizensl@muohio.edu

Briana Kellems
phone number: (513)-260-1088 e-mail: kellembc@muohio.edu
I agree to participate in the study outlined above that looks at swallowing of food and liquids.

I understand my participation is voluntary and that my name will not be connected with my answers.

Participant’s signature ________________________________
Date ________________________________
Appendix C: Parental Questionnaire

I. Identifying Information:

Name of child: ___________________________ Date: __________________
Date of Birth: ___________________________ CA: ______________ AA: __________

II. Medical Information:

1. Does your child have any food allergies?  Yes  No
   If yes, please explain

2. Is your child currently taking any medications?  Yes  No
   If yes, please explain

3. Does your child suffer from seizures?  Yes  No
   If yes, please explain

4. Do you ever notice your child coughing after mealtime?  Yes  No
   If yes, please explain

5. Does you notice a “gurgly” or “wet” voice quality after they eat a meal?  Yes  No
   If yes, please explain

6. Do you notice food or liquid coming out of the nose?  Yes  No
   If yes, please explain

7. Does your child have any type of intestinal, stomach or esophageal problems (such as reflux)?  Yes  No
   If yes, please explain
III. Developmental Milestones

1. What is the main method of communication?
   Speech          Gestures          Sign          None          Other

2. Please indicate the following gross motor skills your child is able to complete:
   Run               Jump

IV. Sensory Skills

1. Would you say that your child gags easily?   Yes   No

2. Is your child a picky eater?     Yes   No

3. Rate how sensitive you feel your child is to the environment?
   1   2   3   4   5   6   7   8   9   10
   Under Sensitive   Normal   Very Sensitive

V. General

1. Which food would your child prefer to eat?   Applesauce   Pudding
   - If pudding, what type would you prefer?   Chocolate   Vanilla

If none, please suggest another pureed food option that can be used:

________________________________________________________________________
Appendix D: Preschool Recruitment Permission Form

__________________________________________ has agreed to allow the ultrasound
(Name of Organization)
team from the Speech Pathology Department at Miami University to communicate with
families and potentially recruit children for a research study involving ultrasound during
swallowing. We allow the ultrasound team to recruit attending children. We understand
that the team will recruit children for the purpose of the approved study only and all
information will be kept confidential.

__________________________________________ (Signature)  __________________________ (Date)

__________________________________________ (Title)