ABSTRACT

ULTRASONIC NORMATIVE SWALLOWING DATA IN THREE/FOUR YEAR OLD CHILDREN

By Stephanie J. Zeidler

This feasibility study will begin to fill a substantial gap within the current swallowing literature to develop normative parameters for hyoid bone movement with ultrasound in children three and four years of age. Twenty-one typically developing children were assessed via ultrasound by two different examiners in a series of bolus presentations. Both hyoid bone excursion and the speed of the excursion were evaluated. Two examiners conducted the ultrasound measurements separately to determine the inter rater reliability across examiners. Results indicated that there was a positive correlation between the examiners conducting the ultrasound measurements. These results support the hypothesis that ultrasound measurements may be duplicated across examiners when a child swallows a single bolus. Furthermore, a consistent bolus size was found to elicit single swallows for this age group, which could have significant clinical implications.
ULTRASONIC NORMATIVE SWALLOWING DATA IN THREE AND FOUR YEAR OLD CHILDREN

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CHAPTER I
Introduction and Review of the Literature

Accurate assessment of swallowing function requires knowledge of anatomical and physiological functions relative to swallowing, expertise in human development throughout the lifespan, and current familiarity with instrumentation tools used to assess dysphagia. The following review of the literature focuses on how the structural integrity of the swallowing mechanism and surrounding systems impacts ability, as well as maturational considerations and etiological implications. Common instrumental tools used to assess pediatric dysphagia and research indicative of ultrasound use as a means of dysphagia assessment and management will also be discussed.

Anatomy and Physiology of the Feeding and Swallowing Mechanism

Deglutition is the act of swallowing, which begins with preparation of a cohesive bolus of food and ends with esophageal transit of the food into the stomach (Dailey Hall, 2001). Structural and physiological integrity of the oral, pharyngeal, laryngeal and esophageal mechanisms are crucial to successful swallowing. Although for most individuals a swallow seems effortless, the physiology of a swallow involves many aspects of the central nervous system, most of the bones of the head and neck as well as approximately 40 paired muscles beginning with the mouth and traveling to the esophagus (Broniatowski et al. 1999). Cranial nerve integrity of the trigeminal (V), facial (VII), glossopharyngeal (IX), vagus (X), and hypoglossal nerves (XII) are also crucial for deglutition (Zemlin, 1997). In order to properly assess and treat individuals with disorders of deglutition, or dysphagia, one must understand the anatomical structures involved in the successful passage of nutrition from the mouth to the stomach.

Structures of Feeding and Swallowing

The oral cavity is comprised of several structures which contribute to the mastication of food, and oral transit of food and/or liquid to the posterior pharynx. The lips, which are innervated by cranial nerve VII (facial nerve), form the orifice of the mouth, and are attached to the alveolar processes of the mandible and maxilla. Labial closure seals the oral cavity for preparation and propulsion of the bolus during a swallow.
The cheeks, or buccae, are the lateral borders of the oral cavity, and provide stability to redirect food during mastication. The cheeks are composed of numerous muscles and subcutaneous fat. Infants have prominent fat pads which reduce the size of the oral cavity, thus creating negative pressure when sucking (Comrie & Helm, 1997).

The tongue is divided into five sections anatomically: the tip, blade, front, back, and base. The tongue is fundamental in deglutition, and is innervated by numerous cranial nerves including: V (trigeminal), VII (facial), IX (glossopharyngeal), X (vagus), XI (accessory), and XII (hypoglossal). There are four extrinsic muscles and four intrinsic muscles of the tongue. The extrinsic muscles are the genioglossus, hyoglossus, palatoglossus, and styloglossus. The intrinsic muscles are the superior longitudinal, inferior longitudinal, transverse, and verticalis. The tongue functions in oral preparation of a bolus, oral transit, and elicitation of the pharyngeal phase of the swallow. Also, the base of the tongue assists in laryngeal elevation and protection of the airway when swallowing.

The mandible, or jaw, is innervated by the third branch of the cranial nerve V (trigeminal). The mandible effects lip posture, tongue positioning, can alter the dimensions of the pharynx as well as assist in depression of the larynx. Mandibular movement allows the tongue to elevate and lower during sucking and mastication. Three particular muscles raise the mandible: the masseter, temporalis, and internal pterygoid. Five muscles lower, but also lateralize, retract and protrude the mandible. These are the external pterygoid, geniohyoid, anterior belly of the digastricus, mylohyoid, and genioglossus. The mylohyoid, in particular forms the floor of the oral cavity.

The faucial pillars are located in the posterior portion of the oral cavity. The anterior faucial pillars, or palatoglossus muscles, are the first and strongest site of sensory stimulation of the swallowing response in older children and adults. For this reason, thermal stimulation is often used to elicit this response when absent (Dikeman & Kazandjian, 2003). The posterior faucial pillars, or palatopharyngeus muscles, are posterior to the anterior faucial pillars along with the palatine tonsils. The palatine tonsils are large in children, but typically atrophy beyond puberty (Bhatnagar, 2002).

The lateral sulci are spaces between the teeth and cheeks. These spaces comprise the buccal cavity. Laterally, the buccal cavity is bounded by the buccinator muscle and
covered with mucous membrane. If any of the muscles of mastication or buccinator muscles are weak, it is possible that food can potentially become lodged in the lateral sulcus areas and cause feeding problems in individuals.

The deciduous teeth consist of lower and upper central incisors (which erupt between 6-10 months of age), the lateral incisors, canines, and first molars (10-20 months of age), and the second molars (20-24 months of age) (Townsend & Hammel, 1990). By 10-13 years of age, these deciduous teeth are replaced with 32 permanent teeth (Townsend & Hammel, 1990). The teeth are necessary for mastication of various textures of foods, and assist in grinding, tearing, and cutting of these consistencies into formation of a cohesive bolus. Three pairs of salivary glands (parotid, sublingual, and submandibular) also help to form a cohesive bolus. These glands, located on the cheeks and the underside of the tongue, provide the lubrication and secretion necessary for managing the bolus. (Dikeman & Kazandjian, 2003).

The pharynx extends from the base of the skull to the cervical vertebrae (C-5 or C-6). The pharynx is commonly subdivided into three sections: nasopharynx, oropharynx, and laryngopharynx. The nasopharynx closes by the way of the velum during a swallow to prevent nasal regurgitation. The oropharynx begins at the posterior faucial pillars and soft palate, and continues to the level of the epiglottis. The oropharynx is composed of the middle constrictor muscles and the vallecular space. The valleculae is located between the base of the tongue and epiglottis. The laryngopharynx, or hypopharynx, is the inferior portion of the pharynx, extending from the epiglottis to the criopharyngeal sphincter, which is the upper most border of the esophagus. The medial and inferior constrictor muscles are housed within the hypopharynx, and are essential components of the swallowing mechanism. The pyriform sinuses are structures formed by the lateral pharyngeal walls and function to direct food around the larynx and into the esophagus.

The laryngeal structures involved in swallowing are the epiglottis, aryepiglottic folds, laryngeal vestibule, true and false vocal folds, and the laryngeal ventricle (Dailey-Hall, 2001). During a swallow, the larynx is elevated to protect the airway by the suprahyoid muscles. Closure of the larynx occurs inferior to posterior. The true vocal folds close initially followed by the false vocal folds, and the epiglottis over the laryngeal
vestibule. The epiglottis is a “leaf-like” cartilage in the uppermost portion of the larynx, and is the first line of defense for the airway when swallowing.

*Embryological and Fetal Development of the Swallowing Mechanism*

The development of the human fetus is a remarkable and astonishing process through which specific forms of maturation take place on a very precise basis. All of the major systems of the human develop within 3 and 8 weeks after fertilization (Dailey-Hall, 2001). An ultrasound study conducted by Comrie & Helm (1997) indicated that the fetus is capable of sucking and swallowing amniotic fluid in utero at 13 weeks gestation, and the volume increases with gestational age. A more recent study which consisted of 69 subjects (62 normal controls and seven at-risk test cases) revealed swallowing in 84.6% as early as 15 weeks 1 day gestational age (Miller, Sonies & Macedonia, 2003). This study also indicated the most active period of swallowing observed between 17 and 30 weeks gestation (Miller, Sonies & Macedonia, 2003).

Between weeks four and eight, six branchial arches develop into the muscles, cranial nerves, and skeleton of the head and neck that are essential for successful swallowing (Bzoch, 2004). Therefore, birth defects involving any of these arches can potentially affect swallowing ability. The first mandibular arch forms the muscles of mastication, the mylohoid, anterior digastricus, tensor veli palatini, and the tensor tympani muscles. Also, the trigeminal nerve (V), the facial bones, and portions of the middle ear (incus, malleus and portion of the stapes) are formed from this mandibular arch (Bzoch, 2004). The second branchial arch is also known as the hyoid arch. This arch forms the muscles of facial expression, posterior digastricus, stylohyoid, stapedius, and levator veli palatini muscles (Bzoch, 2004). The facial nerve (VII), remainder of the stapes, stylohyoid ligament, and the upper portion of the hyoid bone evolve from the hyoid arch (Bzoch, 2004). The third branchial arch comprises the stylopharyngeus and upper pharyngeal muscles as well as the glossopharyngeal nerve (IX) and the rest of the hyoid bone (Bzoch, 2004). The fourth, fifth, and sixth branchial arches comprise numerous muscles associated with the larynx and derives the vagus nerve (Bzoch, 2004).

Important fusions of structures involved in swallowing take place between the 9th and 12th week of development, which is defined as the beginning of the fetal period.
The hard and soft palates, which form the roof of the mouth, fuse at approximately the 12th week in fetal development (Bzoch, 2004). The pharyngeal swallow begins between the 13th and 16th week, and suckling begins as the pharyngeal swallow strengthens in the 17th week (Dailey-Hall, 2001). A study analyzing the in-utero development of thirst and appetite revealed that fetal swallowing activity is markedly diverse from that of the adult (El-Haddad, Desai, Gayle, & Ross, 2004). Spontaneous fetal swallowing occurs at a higher rate (six-fold) compared with spontaneous adult drinking activity. The research indicated that this high rate of fetal swallowing is critical for the regulation of amniotic fluid volume and the development of the fetal gastrointestinal tract (El-Haddad, Desai, Gayle, & Ross, 2004). This allows for sufficient weight gain in the fetus to proceed through the gestational period.

A recent article examined the changing epidemiology of gestational length among singleton births in the United States, based upon data collection from 1992 to 2002. Thirty nine weeks has become the most common length of gestation in 2002, compared with 40 weeks in 1992 (Davidoff, et al., 2006). At birth, the space between all of the structures involved in swallowing is very small, and the tongue fills the oral cavity (Dailey-Hall, 2001). This allows the growing newborn to become accustomed to nasal breathing as well as assist in feeding. Because of the relatively small mandible and fat pads in the cheeks, a newborn infant with intact anatomy and neurologic function should most often become a quick and efficient feeder, because these structures are specifically designed at this age to take a nipple for feeding (Comrie & Helm, 1997). Moreover, primitive reflexes can indicate an infant’s neurologic stability and are often designed to assist the infant in obtaining oral nutrition (Moore & Persaud, 2004). Such infant oral reflexes at term include the gag, phasic bite, tongue protrusion, transverse tongue, and rooting reflexes (Rogers & Arvedson, 2005). Therefore, poor feeding is often thought as the first sign of neurological damage (Comrie & Helm, 1997). The elevated pharynx and larynx provides additional protection of the airway, making aspiration very difficult for the newborn (Dailey-Hall, 2001). Sucking, swallowing and breathing are interconnected by close anatomical associations and shared innervation (Comrie & Helm, 1997). Furthermore, concise coordination of the suck-swallow-breathe pattern is necessary for safe deglutition (Moore & Persaud, 2004).
The Important Role of Respiration in Swallowing

Adequate respiration is fundamental to the successful swallowing of a bolus (Moore & Persaud, 2004). The “centers” that control both respiration and swallowing are located within the medulla of the brainstem (Dailey-Hall, 2001). The typical pattern of respiration and swallowing tends to be consistent in healthy newborns and remains constant throughout adulthood (Comrie & Helm, 1997). Full term infants naturally experience decreases in oxygen saturation as a result of cessation of breathing during acts of swallowing (Comrie & Helm, 1997). Although this is not typically considered an issue with full term healthy infants, desaturation of oxygen levels could potentially pose a problem for the premature infant. Specifically, infants with respiratory rates greater than 60 breaths per minute at rest should not be fed orally (Comrie & Helm, 1997). Respiration rates of this magnitude tend to be more common in premature infants, with conditions such as bronchopulmonary dyplasia (BPD) and respiratory distress syndrome (RDS) (Moore & Persaud, 2004), but can also occur with full term medically fragile infants as well. Breathing takes precedence over feeding in young children with these types of medical difficulties (Comrie & Helm, 1997). Unfortunately, respiration conditions can have lasting effects on a child’s feeding patterns, even well after a child’s medical condition has been resolved (Comrie & Helm, 1997).

Physiology of the Swallowing Mechanism: The Three Phases of Swallowing

Deglutition, or swallowing depends on a highly complex and integrated sensorimotor system and involves four distinct phases: the oral preparatory phase, oral phase, pharyngeal phase, and esophageal phase (Dikeman & Kazandjian, 2003; Rogers & Arvedson, 2005). The oral phase is considered one of the most individualized aspects of swallowing because all individuals are anatomically different. This phase also varies dependent upon what a person intends to swallow and the degree of mastication required to safely swallow a bolus, or ball of food. The oral preparatory phase is not necessary to prepare the food into a bolus (Rogers & Arvedson, 2005). Upon anticipation of food, salivary glands will secrete and lubricate the oral cavity to ease bolus formation. Saliva continues to be produced while the food is masticated, or chewed. Once the bolus has been formed, the second portion of the oral phase; the oral transit stage, may be initiated. This stage is primarily responsible for the movement of the bolus from the anterior to
posterior portion of the oral cavity (Shawker, Sonies, Hall & Baum, 1984). In order for this stage to occur successfully, a labial seal must be maintained, and tension of the buccal musculature must close off the lateral sulci. The tongue tip meets the alveolar ridge, and the posterior portion of the tongue elevates with the soft palate anteriorly pushed against it to keep the substance briefly in the oral cavity. The tongue then initiates a sequence of patterned movements to propel the bolus posterior, which is defined as anterior-to-posterior (A-P) movement. As part of this patterned response, tongue elevation occurs progressively more posterior to push the bolus backward (Shawker, Sonies, Hall & Baum, 1984). This portion of the oral transit phase is typically less than one second. Additionally, sensory feedback is critical for effective management of the bolus in the oral cavity (Rogers & Arvedson, 2005). This feedback occurs via chemical, taste, smell, mechanical, pain, proprioception, and temperature receptors (Rogers & Arvesdon, 2005). Oral phase of the swallow is terminated when the bolus passes anterior faucial pillars triggering the pharyngeal phase of the swallow.

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 or secretions below the level of the true vocal folds (Logemann, 1997). This phase of the swallow is what most people outside of the profession would consider the sole act of swallowing. At the initiation of this phase, several events occur simultaneously.

- The tongue is fully elevated preventing bolus re-entry into the oral cavity.
- The velum closes the velopharyngeal port, sealing off the nasal cavity.
- A narrowing of the upper portion of the pharynx occurs, causing a "plunging" effect which triggers pharyngeal peristalsis. This pharyngeal peristalsis propels the bolus inferiorly towards the upper esophageal sphincter (UES), which is the opening into the esophagus. The tongue and the larynx provide additional pressure to contribute to pharyngeal peristalsis.
- Food is prevented from going into the lungs because anterior and superior movement of the larynx occurs allowing the larynx to close inferior to superior.
- The larynx closes inferior to superior as a defense mechanism to seal off the lungs, and the epiglottis folds over. Respiration therefore ceases for approximately 0.75 seconds to protect the airway (Goldsmith, 2000).
- The pyriform sinuses and valleculae assist in directing the food towards the esophagus. 
- The upper esophageal sphincter and cricopharyngeus relax in order for food to pass into the esophagus, thus ending the pharyngeal phase.

The esophageal phase is the third phase of swallowing. The lowering of the larynx and resumption of respiration begins this stage of swallowing. This phase keeps the esophagus in a peristaltic state of contraction to move the food inferiorly towards the stomach. The cricopharyngeus muscle contracts to prevent reflux. The movement of the food through the esophagus takes approximately 8 seconds (Dikeman & Kazandjian, 2003). 

Multiple levels of the central nervous system are involved within the phases of deglutition (Miller, 1999). The primary afferent cranial nerves include V, VII, IX, and X. The primary efferent cranial nerves for deglutition are V, VII, IX, X, and XII. Movements involving mastication, respiration and swallowing are under the control of specific regions of the brainstem that are defined as pattern generators (Miller, 1999). These central pattern generators are described as an ensemble of neural rudiments that give rise to rhythmical and sequential motor recruitment (Miller, 1999). The primary afferent cranial nerves synapse in the nucleus tractus solitarius (NTS) and the dorsal medullary reticular formation, providing this sequential motor response. Cardiovascular reflexes as well as respiration patterns are simultaneously monitored by the pons and medulla. These complex networks allow for the detailed integration of the distinct phases of deglutition in conjunction with respiration (Rogers & Arvedson, 2005).

**Characteristics of Oral Motor/Sensory Development**

According to a study conducted by Gisel, Birnbaum, and Schwartz (1998), there are four key requirements must exist for successful development of the oral motor/sensory mechanism. The first requirement is the interaction of “stability” and “mobility”. For example, stability of the trunk, neck and head in a young child is
anchored upon sufficient support in the hips and feet. The second requirement is rhythmicity, which begins in infancy (i.e. suckling) and persists in childhood through the chewing of various textures (Schwaab, Niman & Gisel, 1986). Rhythmic movements are neurologically patterned in the tongue musculature, and allow for the adequate A-P movement required for a swallow (Gisel, Birnbaum, & Schwartz, 1998). The third requirement is sensation. Food and/or liquid must be sensed in the mouth for efficient preparation of a bolus. The sensory components of the developing oral cavity have been extensively studied (Gisel, Birnbaum, & Schwartz, 1998). According to this research, sensory innervation is multimodal, and thus serves a multitude of purposes such as taste, temperature, pressure, and stereognosis. However, it is not clear whether loss of one of these modals may lead to functional feeding problems. Studies with children who have oral sensory deficits also have accompanying motor components, as in children with cerebral palsy. Therefore, a motor deficit may make the interpretation of results unreliable because tests of sensation require object manipulation of an object in the mouth. However, recent studies have analyzed the connection between sensations of taste and smell in relation to appetite and perception (Verhagen & Engelen, 2006). Research indicates that odors are frequently associated with the sense of taste in the oral cavity. The loss of smell due, for instance, to blocked nasal cavities, is typically said to result in a loss of ‘taste’ (Deems, 1991). Therefore, interactions within these sensory modalities are common and are highly relevant to food perception (Verhagen & Engelen, 2006). The studies reviewed suggested that multisensory innervation can occur both peripherally (i.e. the effects of lingual temperature on taste) and centrally (i.e. odor enhancement) (Verhagen & Engelen, 2006).

The final requirement for ample oral motor development is oral motor efficiency and economy. The average meal takes no longer than 20 minutes to eat, whether it is an infant or adult consuming it (Gisel, Birnbaum, & Schwartz, 1998). These researchers also indicate that for a child with severe feeding problems, such as in children with cerebral palsy, feeding times up to 7 hours a day have been reported (Reilly, Skuse, & Poblete, 1996). Efficiency of the feeding mechanism is further enhanced by the economy of the system, which means that individuals subconsciously choose the least effortful strategies to accomplish ingestion of various textures of food (Stolovitz & Gisel, 1991). Without
the coexistence of all four of these aspects of the oral motor mechanism, dysphagia can occur as a result of insufficient oral motor skills. 

**Feeding Maturation**

The acquisition of age appropriate feeding skills is fundamental to an infants’ development of self regulation and independence (Rogers & Arvedson, 2005). Upon neurologic maturation, the transition from infancy to preschool age allows for more efficient feeding abilities, specifically with more lip control, increased mobility of the tongue which assists in more efficient anterior-to-posterior movement of the bolus, and decreased involvement of circumoral structures (lips and cheeks). Normal feeding development proceeds from suckling behaviors and purely liquid diets to chewing solid foods and differenting textures (Stolovitz & Gisel, 1991). This development of functional feeding reflects the maturational achievements in sensorimotor integration of swallowing and respiration, hand-eye coordination, normal muscle tone and posture, and appropriate psychosocial maturation during the initial three years of life (Arvedson & Brodsky, 2002; Carruth & Skinner, 2002). Stolovitz and Gisel (1991) indicated that in a study of 143 healthy children two years of age or less, the most frequent behaviors used to swallow were pursing lips together and drawing the lower lip inward. Children at this age are still learning how to mobilize their tongues and therefore must rely more heavily on circumoral structures such as their lips or cheeks. With regards to tongue mobility, children mature specifically in the lateralization of their tongue as they age. A more recent study conducted by Carruth and Skinner (2002) studied the key milestones of functional oral motor development. Most infants by 7-9 months of age can be given liquids by a cup secondary to sufficient ability to achieve mouth closure around a rim. Moreover, chewing appears with up and down diagonal rotary movements by 12 months of age (Arvedson & Brodsky, 2002), which coincides with the emergence of tongue lateralization (Carruth & Skinner, 2002). The constant changes in the dynamics of swallowing provide children with the ability to swallow various textures with ease due to easy manipulation as well as assertive control of a bolus (Stolovitz & Gisel, 1991).

Stolovitz and Gisel (1991) found a correlation between poorer circumoral scores and longer feeding times. Therefore, children who continue to depend highly on circumoral structures with regards to swallowing have longer feeding times, and are considered less
efficient in deglutition. Poorer control of the bolus, in addition to increased feeding time and decreased efficiency of the structures involved in swallowing places a child at risk for aspiration. This particular study emphasizes the impact that a poor oral phase of swallowing has on nutrition and overall swallowing patterns.

**Pediatric Dysphagia**

According to an article published by the Journal of American Medical Association, increasing medical and technological advances in medicine are significant contributors to the increase of survival rates among medically fragile newborns, and these figures are increasing each year (“Healthier Mothers and Babies”, 1999). This advance in medicine now provides the infant a chance to survive outside of the womb as early as 23 weeks as a result of this increased survival and medical care (Gultom, Doyle, Davis, Dharmalingham, & Bowman, 1997). An increase in infant swallowing disorders persists. Infants often have multiple health issues and an increased risk of respiratory complications, all of which contributes to the likelihood of pediatric dysphagia (Newman, Keckley, Petersen, & Hamner, 2001). If not treated, or if severe in nature, these conditions persist well into an infant’s life and may manifest during periods of most active growth, i.e. from birth to 2 years and during the adolescent growth spurt (Gisel, Birnbaum, & Schwartz, 1998). These time periods are critical and may have lasting effects on nutrition and survival (Comrie & Helm, 1997). This subsequently increases the demand for services; specifically early intervention considering the fact that research shows that growth and development are most rapid in the early years of life (Dailey-Hall, 2001).

As illustrated, swallowing and respiration are fundamental aspects of well-being, growth and survival. Dysphagia defined is impairment of the swallowing mechanism (Bhatnagar, 2002). This dysfunction of swallowing in infants may occur as a result of a variety of neurological deficits, structural anomalies, or premature feeding patterns (Arvedson, Rogers, Buck, Smart & Msall, 1994). Dysphagia in infants and children encompasses a variety of difficulties associated with eating and may include any of the following symptoms: failure to thrive, difficulty sucking, meal-time distress, spitting, vomiting, difficulty chewing food, swallowing solids and/or liquid, coughing, choking or gagging when eating, refusing food, excessive oral secretions, oral-tactile
hypersensitivity, food getting stuck in the throat or chest, aspiration-related respiratory conditions, and/or gastroesophageal reflux (Logemann, 1997; Sonies, 1997). The American Speech-Hearing Association (ASHA) estimates that approximately fifteen million Americans have dysphagia (Division 13).

Feeding and swallowing disorders are relatively common in early infancy and can have long-lasting health implications (Rogers & Arvedson, 2005). In a follow-up study of 283 preterm infants, 33% of parents reported feeding problems characterized by swallowing difficulties and refusal of food (Wood et al., 2003). These feeding problems were linked to poorer growth outcomes at 30 months of age. Parents and caregivers have also reported a high incidence of feeding problems (60%) in infants with “non-organic failure to thrive” (Rogers & Arvedson, 2005). Further, children with cerebral palsy, congenital heart disease, or kidney problems have an even higher risk for malnutrition, growth failure, dehydration, weight loss, airway obstruction, and poor health (Rogers & Arvedson, 2005). Often, the most life-threatening cause of dysphagia is aspiration pneumonia. Aspiration is defined as the entry of material into the airway below the level of the true vocal folds (Arvedson, Rogers, Buck, Smart & Msall, 1994). Acute pneumonia and chronic lung disease may result from persistent aspiration (Arvedson, Rogers, Buck, Smart & Msall, 1994).

Deglutition has both voluntary and involuntary components that must intricately interact. Therefore, a child with a medical condition may develop life threatening, long-lasting, and serious health issues as a result of dysphagia. Normative data collection in healthy individuals is necessary to tackling the feeding problems often present in various medical diagnoses. A study analyzing swallowing patterns with regards to cerebral palsy and neurologically normal children recently stated, “Little data exists on the oral management of food boluses in neurologically normal children or children with CP” (Casas, McPherson & Kenny, 1995). Ultrasound provides data on oral and pharyngeal control of a bolus that may be useful with the management of swallowing disorders in children.
Possible Etiologies of Pediatric Dysphagia

Pediatric dysphagia can be a result of structural, physiological, and/or behavioral issues (Sonies, 1997). Specifically, children with medical conditions may pose a significant risk, since these ages are still growing accustomed of how to eat and have not over learned the task throughout their lives as adults have. Many disorders and syndromes can disrupt the successful process of feeding and digestion. These disorders can be a result of gastrointestinal, respiratory, central nervous system damage, prematurity, structural abnormalities, or cardiac issues (Dailey-Hall, 2001). Moreover, over half of neurologically impaired children have feeding difficulties (Yang, Loveday, Metreweli, & Sullivan, 1997).

Pathologies and syndromes encountered in pediatric dysphagia associated with deficiency in oral motor competency have been divided into several distinct categories (Gisel, Birnbaum & Schwartz, 1998). These categories include central nervous system complications, genetic conditions, syndromes, traumatic brain injuries, and children with developmental delays.

Children with encephalopathies, or diseases of the central nervous system may be acute or chronic and are caused by perinatal asphyxia, infection, severe jaundice, brain tumors, or congenital degenerative diseases (Dailey Hall, 2001). For example, cerebral palsy is an encephalopathy seen in children who have accompanying dysphagia. The prevalence of dysphagia has ranged from 57% to 92% depending on the type of cerebral palsy (Reilly, Skuse & Poblete, 1996; Sullivan et al., 2002; Fung et al., 2002).

Genetic conditions which may affect feeding and swallowing include the muscular dystrophies, trisomies, and familial dysautonomia. According to the National Institute of Neurological Disorders and Stroke (Electronic version), the muscular dystrophies (MD) are a cluster of over 30 genetic diseases characterized by “progressive weakness and deterioration of the skeletal muscles that control motor movement.” Trisomies refer to the presence of three chromosomes, rather than the typical pair of chromosomes (Moore & Persaud, 2004). Down syndrome, also referred to as Trisomy 21, is the most common chromosomal syndrome (Jones, 1997; Rosetti, 2001). Familial dysautonomia, or FD, is characterized by widespread sensory dysfunction and
inconsistent autonomic dysfunction caused by deficient development of sensory and autonomic neurons (Moore & Persaud, 2004).

Traumatic brain injuries resulting from instances such as motor vehicle accidents or asphyxia from drowning can also be a potential etiology for dysphagia. Often these patients show distinct difficulty with swallowing, and therefore require immediate attention for adequate nutrition. Dependent on the severity of the accident, a child may have residual damage in areas of cognition and/or swallowing which is of prime interest to the speech-language pathologist.

An equally important etiology, although more vague in nature, exists when children are orally deprived or sensory defensive. Infants or toddlers may present with behavior state changes and gagging in response to tactile stimulation to oral and/or surrounding body regions (Scarborough et al., 2006). Often these children are born premature and initially tube fed longer than four weeks (Gisel, Birnbaum & Schwartz, 1998). However, research also suggests that sensory defensiveness can exist in full term infants with or without co-existing conditions (Gisel, Birnbaum & Schwartz, 1998). Many of these children are described as “picky eaters” and refuse food when offered due to increased hypersensitivity of the oral mechanism. Although eventually pureed and liquid consistencies may be accepted, typically these children will continue to refuse various textures and foods which require mastication prior to the swallow (Gisel, Birnbaum & Schwartz, 1998). Recent data established that children with persistent feeding problems often exhibit an abnormal touch response pattern (Scarborough et al., 2006).

Clinically, many of these children are in speech therapy at an older age due to hypersensitivity and/or hyposensitivity of the oral mechanism, and much anxiety coincides with eating for these children. Therefore, even though these children are mechanically intact and capable of eating, a feeding disorder still exists due to the lack of oral exposure at a young age. These children may be labeled as having a developmental delay and consist of a large group who often remain undiagnosed but do not have the feeding skills appropriate to their chronological age (Gisel, Birnbaum & Schwartz, 1998). Rosetti (2001) describes these children as “at risk” because no specific syndrome or known etiology is present that would place them in the “established risk” category.
However, these children may have numerous biological and/or environmental factors that contribute to a developmental delay (Rosetti, 2001). Although not all inclusive, some examples of factors that place a child at risk for developmental delay are lack of stable residence, inadequate caregiving (parent/caregiver with alcohol/drug dependence, parent/caregiver with history of abuse, parent/caregiver with severe or chronic illness) that may affect parent/child interaction, or chronic otitis media (Rosetti, 2001).

The potential causes for dysphagia are vast and numerous. Research in recent decades has improved our understanding of how underlying etiologies may have an impact on feeding and swallowing. However, normative data, specifically with respect to ultrasound research, is somewhat limited in comparison, specifically for children (in comparison to infants and adults). Normative data is necessary to fully understand how children with dysphagia differ in comparison to their age-matched peers without feeding delays.

Assessment of Pediatric Dysphagia

Dysphagia may be characterized by severity and location (oral, pharyngeal, or esophageal). The speech-language pathologist assesses dysphagia within the realm of oral and pharyngeal stages of swallowing, and is the professional of the health care team responsible for assessment and treatment of the swallowing problems (Dikeman & Kazandjian, 2003). Management of dysphagia is achieved by first screening the patient to identify those at risk, and then proceeding with a more thorough diagnostic evaluation to determine the basis of the swallowing problem, as well as establish effective treatment procedures or techniques to be used (Swigert, 2000).

Understanding of the relationship of the child’s feeding performance to overall developmental functioning is an important aspect of a child’s feeding/swallowing assessment (Gisel, Birnbaum & Schwartz, 1998). Arvedson (2000) developed a thorough evaluation for children with feeding and swallowing problems. Each piece contributes to the ability to classify a child as having a mild, moderate, or severe feeding delay based upon normal maturational growth and integrity (Gisel, Birnbaum & Schwartz, 1998). Two distinct portions of the assessment are the clinical examination, and the use of instrumental procedures to diagnose dysphagia.
A clinical feeding evaluation is a critical segment of a thorough diagnostic assessment. The clinical assessment begins with a thorough medical, developmental, and feeding history (Arvedson, 2000). An in-depth case history is vital for a thorough evaluation. Collecting information regarding current status, social history, medical history, and the feeding/swallowing history of the child is important to be able to make accurate judgment regarding the etiology of the problem (Daile-Hall, 2001). Current status allows the clinician to gather present concerns from the parent as well as reason for referral (Arvedson, 2000). The social history aspect of the case history provides important information about the family dynamic, home environment and feeding environment (Arvedson, 2000). This information is helpful for planning effective intervention. Medical history establishes certain diagnoses the child may have, as well as pregnancy related issues or illnesses the child may have experienced that could potentially contribute to the current problem. Current medications the child is on, allergies, sleep patterns, motor development, and speech/language development are all included under collection of medical history (Arvedson, 2000).

The next piece of the clinical evaluation is a physical examination which is guided by the feeding and medical history (Arvedson, 2000). Integrated pieces of the physical examination include behavior/state/sensory integration, general postural control/tone, respiratory function/endurance, an oral motor/cranial nerve evaluation, and a feeding/swallowing evaluation (Dailey-Hall, 2001). Regardless of the age of the child, a standard pediatric clinical evaluation of feeding and swallowing consists of case history, physical examination (with overall developmental assessment of above areas mentioned), the observation of swallowing, combined with medical and parental input (Rogers & Arvedson, 2005).

Behavior/state/sensory integration permits observation of the state of alertness (particularly when feeding), stress cues before or after feeding, and response to touch or stimulation (Rogers & Arvedson, 2005). The goal is to rule out hyposensitivity or hypersensitivity as factors affecting feeding (Dailey-Hall, 2001).

Observing general posture and/or tone is also important considering misalignment of the system can significantly impact a child’s ability to eat. The head should be situated loosely in a forward position. The shoulders should be symmetrical and slightly
downward. Ideal positioning is seated in a chair, with a stable trunk and alignment of the head, neck and spine. The feet should be supported and the pelvis at a 90 degree angle. Pelvic alignment is the first focal point because the pelvis provides a stable base for the entire body (Alexander, Boehme & Cupps, 1993).

The respiratory function and endurance, as previously discussed, has a tremendous impact on a child’s ability to feed. In order for the pharyngeal phase of swallowing to occur, respiration must cease. This is particularly difficult for the child with respiration difficulty. Clinical manifestations of dysphagia in infants are primarily apnea and bradycardia during feeding (Loughlin & Lefton-Greif, 1994). Observation of respiratory patterns before, during, and following feedings is important for accurate clinical judgment. If able, pulse oximetry is also useful in tracking a patient’s cardio-respiratory status while eating. Pulse oximetry is a measurement arterial blood oxygenation levels (Dikeman & Kazandjian, 2003). Research indicates that pulse oximetry can be helpful in monitoring the tolerance of oral feeding over a period of time (Dikeman & Kazandjian, 2003).

The oral motor and cranial nerve examination evaluates persistent primitive reflexes that may interfere with eating, oral structure and function, and screening of cranial nerve integrity (Arvedson, 2000). Any deficits in the swallowing mechanism are important to acknowledge so that compensatory measures can be correctly applied in a treatment program.

For the clinical evaluation of feeding and swallowing, assessment of the oral and oral preparatory phases can be performed as well as pre-feeding observations discussed by Arvedson (2000). Although no single test or scale of feeding difficulties is available, there are a number of checklists and rating scales available to assist in standardizing the clinical examination of feeding and swallowing (Arvedson & Brodsky, 1993; Arvedson & Lefton-Greif, 1998; Chatoor, Menevielle, Getson, & O’Donnell, 1989; Cherney, 1994; Herman, 1991; Jelm, 1990; Kenny, Casas, & McPherson, 1989, Lowman & Murphy, 1999; Morris & Klein, 1987; Rosenthal, Sheppard, & Lotze, 1995; Swigert, 1998; Tuchman & Walter, 1994; Warner, 1981; Wolf & Glass, 1992). Cervical auscultation can also augment a feeding evaluation. In this procedure, a pediatric stethoscope is placed in
close proximity of the larynx and the sounds of both swallowing and respiration may be observed (Dailey-Hall, 2001).

However, assessment of the pharyngeal phase, and/or underlying oral difficulties that is not as easily visible are a hindrance of a clinical evaluation. Therefore, in this situation, an objective instrumentation may be needed to fully determine the etiology of the problem.

**Common Instrumental Assessment Tools**

At the present time, there are two widely used procedures to assess the pharyngeal phase of the swallow: the video fluoroscopic examination or video swallow study (VSS) and the fiberoptic endoscopic evaluation of swallowing (FEES). The “gold standard” for evaluation of swallowing disorders is the video swallow study. For the VSS, a patient swallows various textures of barium saturated food and/or liquid so that the bolus may be perceived on the screen by a licensed radiologist and speech-language pathologist (Swigert, 1998). In the FEES procedure, an endoscope is passed through the nasal cavity for view of the pharynx while the patient swallows food or liquid, which is often dyed for better visualization (Swigert, 2000). Both procedures supply a wealth of information about the pharyngeal aspects of the swallow. However, neither the FEES nor VSS provide detailed information about the oral and oral preparatory stage of the swallow or the soft tissues associated with swallowing. Furthermore, the VSS exposes the patient to radiation and therefore poses limitations (Stolovitz & Gisel, 1991). X-ray visualization of the oral soft tissues may be obscured by dental appliances, magnification errors hampers spatial measurements, and finally there may be poor definition of the contrast material because of tongue curving (Shawker, Sonies, Hall & Baum, 1984).

Four other instrumental techniques exist that are used to assess other crucial aspects of swallowing. Electromyography (EMG) provides information about the contraction of a muscle or muscle group. Pharyngeal manometry measures the pressure in the upper and lower esophageal sphincters. Scintigraphy allows for measurement of the amount of material aspirated. Finally, ultrasound produces dynamic images of the soft tissues (Swigert, 2000). Such instrumental procedures to assess swallowing are often utilized considering a bedside, or clinical evaluation poses significant limitations.
**Ultrasonography**

Ultrasound is a method of obtaining images from within the body without the exposure of ionizing radiation. Ultrasound is gaining popularity in the field of speech-language pathology as a research tool (Bressman, Heng, & Irish, 2005). Recent and continuous advances in computer technology makes ultrasound a more appealing option for visualization of various anatomical structures related to swallowing (Bressman, Heng, & Irish, 2005).

**History of Ultrasound**

Throughout the decade of the 1970’s ultrasound imaging of the tongue was used for speech research (Shawker & Sonies, 1984; Shawker & Sonies, 1985). A variety of instrumentations were utilized including bistable static B-scanners, through transmission M-Mode units, and gray scale static B-scanners. In 1980, real-time scanning instrumentation was introduced in imaging of the tongue (Shawker & Sonies, 1984). This includes the use of a linear array transducer and a mechanical sector transducer (Shawker & Sonies, 1984).

**Potential Uses for Ultrasound**

Since ultrasound does not expose the patient to radiation, it is often used to visually capture images of such internal organs and tissues including but not limited to the heart, liver, gallbladder, spleen, pancreas, kidneys, and bladder (Wade, 2000). Moreover, obstetric ultrasound imaging allows visualization of the human fetus necessary for monitoring fetal development (Wade, 2000). Real-time imaging provides detailed information regarding movement of internal tissues and organs, and can even provide physicians information regarding blood flow and heart valve functions (Wade, 2000).

**Revolutionizing Ultrasound for Swallowing Research**

A physical impulse into the atmosphere will place any object into oscillation and results in echoes. In order to obtain an image using ultrasound, these echoes are sound waves that are dispersed at frequencies above that audible to the human ear (over 20 kHz). A transducer first generates this sound, and then the piezoelectric crystal of the transducer receives the sound waves via echoes, that are transmitted through the structures of the human body. A computer then reconstructs the images on the screen for the diagnostician, or researcher, to view. Real time ultrasound imaging displays the
movement of anatomic structures, muscles, and tissues by this method (Bressman, Heng & Irish, 2005). In recent years, researchers have discovered that ultrasound may be utilized to efficiently assess and manage swallowing patterns and disorders by placing the transducer below the chin to capture visualization of many structures including the tongue, hyoid bone and mandible (Bressman, Heng & Irish, 2005). Considering the hyoid bone is a point of attachment for various muscles involved in deglutition, ultrasonic measurements provide a wealth of information concerning the swallowing patterns and safety of the patient (Chi-Fishman & Sonies, 2002B). Particularly, the hyoid bone is well seen in the sagittal plane and its movement acts as an indicator for the integrity of the hyoid/larynx/epiglottis unit. Elevation of this unit is thought to be the single most important dynamic in airway protection during a swallow (Yang, Loveday, Metreweli, & Sullivan, 1997). The hyoid bone can also be viewed in real-time, and it is therefore possible to make a more accurate judgment of the swallowing reflex using ultrasound. Measurement values pertaining to temporal distance in milliseconds as well as distance of the movement of the hyoid bone are applicable uses of ultrasound to assess a person’s ability to swallow efficiently. Real-time visualization as well as frame-by-frame analysis allows detailed depictions of swallowing patterns and has implications for diagnosis and treatment of those with swallowing disorders.

Furthermore, technological advances and demand for ultrasonic machinery have significantly reduced the cost and thus allowed for greater access to this equipment (Bressman, Heng & Irish, 2005). Ultrasound is a non-invasive technique which can be used extensively with a patient. For these reasons, ASHA’s position statement and guidelines for ultrasonagraphy indicate that this technique is useful as a biofeedback tool for viewing and studying lingual motion, temporal aspects of the oral and pharyngeal swallow, bolus transport, and laryngeal closure. This procedure offers much exciting potential for researchers and therapists in speech-language pathology.

The ultrasound procedure has been utilized in the medical community for a number of years as a non-invasive diagnostic and clinical procedure. Real-time image acquisition has expanded the realm of phonetic research by examination of tongue shapes relative to various speech sounds (Morris, Stone, Sonies, Kurtz, & Shawker, 1984; Shawker & Sonies, 1984) and also to identify sequential aspects in motor control of
speech (Parush & Ostry, 1986). To date, a significant number of ultrasound studies have been published with regards to the adult population (Chi-Fishman & Sonies, 2002A; Chi-Fishman & Sonies, 2002B; Chi-Fishman, Hicks, Cintas, Sonies, & Gerber, 2004; Cordaro & Sonies, 1993; Frattali, Sonies, Chi-Fishman, & Litvan, 1999; Hicks, Shawker, Jones, Linzer, & Gerber, 1984; Kuhl, Eicke, Dieterich, & Urban, 2003; Shawker, Sonies, Stone & Baum, 1983; Shawker, Sonies, Hall, & Baum, 1984; Soder & Miller, 2002; Sonies, Parent, Morrish, & Baum, 1988; Sonies, Wang & Sapper, 1996). Many studies have also focused specifically on tongue movement in the oral phase of swallowing (Casas, Kenny, & Mcmillan, 2003; Chi-Fishman, Stone, & McCall, 1998; Neuschafer-Rube, Wein, Angerstein, Klagman, & Fischer-Wein, 1997; Wein, Klagman, Huber & Doring, 1988; Peng, Jost-Brinkmann, Yoshida, Miethke, & Lin, 2003; Stone & Shawker, 1986).

Moreover, many studies have been conducted analyzing suckling behaviors in newborns (Bu’Lock, Woolridge, & Baum, 1990; Bosma, Hepburn, Josell, & Baker, 1990; Smith, Erenberg, Nowak, & Franken, 1985; Weber, Woolridge, & Baum, 1986). Certain pathologies have also gained attention in the ultrasonic research such as cerebral palsy (Casas, Kenny & McPherson, 1994; Casas, McPherson & Kenny, 1995; Kenny, Casas, & McPherson, 1989), glossectomy (Bressman, Uy & Irish, 2005), and strokes (Wein, Klagman, Huber & Doring, 1988).

Considering a wide variety of diseases which may affect the oral structures of the mouth, specifically the nerve supply, analysis of the oral phase of swallowing and the ability to form and propel a bolus posteriorly is critical to swallowing management. Ultrasound is a helpful tool, because instead of visualizing the bolus (as in radiography), ultrasound visualizes the soft tissues and structures with emphasis on the anatomy and physiology of the patient.

A study conducted by Shawker, Sonies, Stone, & Baum (1983) compared normal adult subjects to a subject with a neurological impairment and found that differences in structural integrity were measurable and significant utilizing ultrasonography. Moreover, this study highlights the importance of the oral phase of swallowing, and implies that this stage of swallowing is often overlooked or de-emphasized when utilizing other procedures such as video-fluoroscopic examination (Stone & Shawker, 1986).
Therefore, potential therapeutic techniques within the oral phase of swallowing may not be recognized. If the patient has significant difficulties in the oral phase, therapy to stabilize and strengthen the oral structures may be useful in preventing difficulties in later stages of swallowing and thus prevent aspiration. Considering the many anatomical changes that take place during normal maturation, treatment of pediatric dysphagia can be more challenging (Dailey-Hall, 2001). Ultrasound can evaluate the effects of oral sensory motor stimulation techniques and study the sucking patterns of preterm infants (Dailey-Hall, 2001). Ultrasonography is a means to obtain this information diagnostically and treat the patient therapeutically to stabilize and effectively manage the oro-pharyngeal stages of swallowing. Unfortunately, current data focuses primarily on adult application and limited data exists regarding children and the use of ultrasonography.

Advantages and Disadvantages of Ultrasound in Dysphagia

When utilizing ultrasound, because of surrounding bone and air in the oral cavity, the only practical method of scanning the tongue is from the submenthal position (Shawker & Sonies, 1984). This specific positioning can limit views of some structures. For example, the palate is not visible unless the mouth is filled with water, and the tongue and palate have contact (Shawker & Sonies, 1984). Another factor that may impact results is varying the placement of the transducer in relationship to coronal and sagittal planes of the child, since any angulation of the beam from midline will produce measurement variability (Shawker & Sonies, 1984, Stone & Shawker, 1986). This shortcoming, however, may be easily remediated by the examiner by careful placement of the transducer underneath the chin to ensure accuracy. The most significant drawback of ultrasonic imaging for clinicians is that ultrasound does not easily detect laryngeal penetration and/or aspiration (Loughlin & Leifton-Grief, 1994).

However, the benefits of ultrasound largely outweigh the disadvantages. Ultrasound is a non-invasive, easy to use and widely available procedure (Barnett et al., 2000). By using this procedure, one can visualize the tongue’s wave-like motion during the oral phase of swallowing (Shawker, Sonies, Stone & Baum, 1983). Also, barium contrast is not needed to emphasize the bolus in the oral cavity, and therefore clinicians can use food and/or beverage from the patient’s regular diet, providing a more naturalistic situation for the swallow (Casas, Seo, & Kenny, 2002). By gathering normative data, this
examination of the tongue blade as it reacts to a bolus can provide a baseline against which to compare abnormal swallowing patterns (Stone & Shawker, 1986). In addition, ultrasound provides a plethora of information regarding the safety of a patient for feeding by the movement of the hyoid bone because the hyoid bone is the point of attachment for various muscles and tissues of the floor of the mouth, tongue, and larynx.

Summary

Dysphagia consists of an impairment of the swallowing mechanism (Bhatnagar, 2002). This impairment may result from anatomical and/or physiological components that occur anywhere from the oral cavity to the stomach. Pediatric dysphagia often co-exists with numerous other problems in children, but can exist alone. By 15-24 months of age, a child should be able to successfully drink from a cup independently with sufficient jaw stability, as well as self feed with kitchen utensils such as a fork and spoon (Dailey-Hall, 2001). Children that do not reach this developmental aspect in maturation may be significantly comprised for nutritional and growth needs. More research concerning the feeding and swallowing disorders in children is vital to establish optimal management techniques in evaluation and treatment in pediatric dysphagia.

Ultrasonography uses sound waves to create images of the body, and has been utilized in the medical community for a number of years as a non-invasive diagnostic and clinical procedure. In recent years, researchers have discovered that ultrasound may be utilized to efficiently assess and manage swallowing patterns and disorders by placing the transducer below the chin to capture visualization of many structures including the tongue, hyoid bone and mandible. Real time ultrasound imaging displays the movement of anatomic structures, muscles, and tissues (Bressman, Heng & Irish, 2005). This visualization as well as frame-by-frame analysis allows detailed depictions of swallowing patterns and has implications for diagnosis and treatment of those with swallowing disorders. Unfortunately, limited data exists utilizing ultrasound to assess, diagnose, and treat children with dysphagia, and this gap in the literature necessitates further research.

Statement of the Problem

Despite the vast amount of research dedicated to ultrasonography mentioned previously, limited data has been collected thus far regarding young children with
swallowing abnormalities (specifically preschool-age children). This gap in the literature necessitates further research (Scarborough, 2006).

Purpose of the Study

The purpose of the present study was to obtain normative data on swallowing function in healthy three and four year old children using ultrasonography to compare the duration and height measurements of the child’s swallow as well as measurement of time. Individual variances between these children were calculated. Additionally, this study determined the inter-rater reliability between two people conducting the measurements of the ultrasound equipment.
CHAPTER II
Methods and Procedures

Participants

The participants for the present study included a total of 21 children, between 3 and 4 years of age. Subjects were recruited from local Greater Cincinnati area preschools by distribution of flyers with consent of the preschool’s director. All subjects were screened to determine eligibility and informed consent was obtained from the child’s parent/guardian.

Inclusion Criteria for all Participants:
1. Healthy males and females between 3-4 years of age.
2. Negative significant medical history indicative of a feeding disorder.
4. From a feeding perspective, the child should be feeding upright, self-feeding and have volitional control of oral musculature.

Exclusion Criteria for all Participants:
1. Positive medical history for neurological problems, congenital defects, sensory disorders, and/or any conditions associated with feeding problems.
2. History of speech and/or language disorders.
3. Any child over 4-years old or under 3-years old.

Measurements and Procedures

Questionnaire

The purpose of the questionnaire was to screen normal controls. Questionnaires were sent home and filled out by a parent after informed consent forms were returned to the preschool. The questionnaire took approximately 5 minutes to complete.

Oral Motor Sensory Screening

Subjects underwent a brief oral sensorimotor screening that was utilized as part of standard clinical evaluation. This screening focused on anatomical relationships such as symmetry and proportionality as well as sensory and motor skills to ensure that they were within developmental norms. This oral motor examination for facial symmetry and structural abnormalities was completed via visual inspection. Complete intraoral
examinations were not included (i.e. palatal inspection) due to the invasive nature of this procedure.

The oral motor sensory screening took less than 5 minutes to complete.

*Ultrasound*

Ultrasound information was collected using a portable Aloka 900 SSD with a pediatric probe (type UST 987-7.5 MHz, 65 degree, 20 mm radius) and Sony SVO 9500MD videocassette recorder. The probe depth was placed at 5 cm in order to obtain a more detailed view of the hyoid bone and posterior tongue (Frattali, Sonies, Chi-Fishman & Litvan, 1999). The probe was placed in two planes of reference for the study: a) midsagittal view, and b) coronal view. In the midsagittal view duration and height measurements of the hyoid bone of each swallow were obtained. A frame-by-frame analysis began at the point when the hyoid bone first moved to when it returned to the resting position (Shawker, Sonies, Hall & Baum, 1984; Chi-Fishman & Sonies, 2002B). This procedure was standardized across examiners using a 1:1 ratio, using the exact same marking system between trial one and trial two. In the coronal view a combination of B-mode and M-mode were simultaneously captured. The B-mode allowed for anatomic viewing of the base tongue/hyoid shadow (this shadow can be measured to ensure accuracy of the probe angle) and the M-mode allowed discrete measurements over time of base of tongue movements during a swallow(s) as well as time measurement of latency between swallows. The time measurements of the hyoid bone in the coronal view have been studied in the pediatric/adult population only recently (Scarborough, 2006). The simultaneous B/M mode is a relatively new feature of the machine and therefore has not been available for previous studies until recently. Thus, durational (time) results gathered with the coronal view (via the simultaneous B/M mode) were compared hand-calculated time results of the midsagittal view.

All subjects were seated upright in a chair. For each plane of reference, midsagittal and coronal, two boluses of each of the following single swallow trials size of pureed food were presented via maroon spoons. The task order for the discrete swallows were randomized. Two separate trials were conducted so that inter-rater reliability could be tested (see below). Randomly assigned models were utilized to encourage participation (i.e. live model, baby doll model, or no model).
Examiner 1 (Examiner 2 was blinded to examiner 1 collecting data)

5 Swallows

- Dry Swallow x 1
- 2.5cc x 1 B Mode
- 2.5cc x 1 M Mode
- 5.0cc x 1 B Mode
- 5.0cc x 1 M Mode

Examiner 2 (Examiner 1 was blinded to examiner 2 collecting data)

5 Swallows

- Dry Swallow x 1
- 2.5cc x 1 B Mode
- 2.5cc x 1 M Mode
- 5.0cc x 1 B Mode
- 5.0cc x 1 M Mode

Breaks were given as needed. Examiners alternated between swallows to collect the data in an efficient manner. The ultrasound portion of the study took approximately 20 minutes to complete but varied upon individual subject, cooperation and number of breaks required. Overall, the study took 20-40 minutes to complete.

**Research Questions**

1. What are the normal parameters that should be observed when assessing using ultrasound measurements in 3 and 4-year old children?
   i. What is the normal parameter when assessing a dry swallow?
   ii. What is the normal parameter when assessing a 2.5 cc swallow
   iii. What is the normal parameter when assessing a 5.0 cc swallow?

2. Can ultrasonic measurements be duplicated across examiners?

**Data Analysis**

Statistical analyses were carried out utilizing the Statistical Package for Social Science (SPSS 14.0 for Windows). Descriptive statistics and a multivariate analysis of variance (MANOVA) was completed to allow for detailed analysis of differing swallows
dependent upon bolus size (2.5 and 5.0cc) and variances between individuals. Additionally, a Pearson Product-Moment Correlation was completed to calculate the correlation amongst the two examiners calculating the ultrasound measurements.
CHAPTER IV

Results

Thirteen participants were female and 8 participants were male. The average age of the participants was 3.72 years (SD= 0.52, range 3.04-4.39 years.) There was no significant difference between the ages of the males versus the female participants. Subjects had no significant feeding history and normal muscle tone. From a feeding perspective, these children were eating upright, self-feeding and had volitional control of oral musculature.

**Research Question 1: What are the normal parameters that should be observed when using ultrasound measurements to assess swallowing in three and four year old children?**

For the purpose of normative data, the present study calculated descriptive statistics for means of comparison between the two individuals conducting the ultrasound measurements (trial one and trial two).

**i. What is the normal parameter when assessing a dry swallow?**

Next, B-mode ultrasound measurements allowed for capture of the swallow in real-time, and are a measurement of the distance of hyoid bone movement from initiation to end of the child’s swallow. For the dry swallow performed in B-mode, the average measurement for trial one was 1.119 cm (SD= 0.470) with a range of 0.90-2.12 cm. The average measurement for trial two was 1.0115 cm (SD=0.3946), with a range of 0.470-1.70 cm. One participant did not comply for the second trial, and therefore examiner 1 results were based on 21 subjects whereas examiner 2 results were based on 20 subjects.

**ii. What is the normal parameter when assessing a 2.5 cc swallow?**

Measurements taken for a bolus size of 2.5 cc of pureed food revealed a mean measurement of 1.1095 cm (SD= 0.4295) for trial one and 1.1905 cm (SD=0.3638) for trial two. Ranges for trial one were between 0.490 and 2.240 cm. For trial two, ranges were between 0.770 and 2.140 cm.

The M-mode setting measures the amount of time (ms) taken for a person to complete a swallow from start to finish. With respect to a bolus size of 2.5 cc, trial one resulted in a range of 313.0-766.0 ms and a mean measurement of 480.2 ms (SD=117.9).
Trial two averaged 483.6 ms (SD=94.7) for a 2.5 cc bolus, with a range of 320.0-680.0 ms.

**iii. What is the normal parameter when assessing a 5.0 cc swallow?**

Mean measurements for a 5.0 cc bolus were 1.256 cm (SD=0.540) and 1.289 cm (SD=0.543). Ranges for trial one were between 0.58 and 3.09 cm. Measurement ranges for trial two were between 0.61 and 2.77 cm, respectively. Measurements were based on compliance of 19 participants.

A 5.0cc bolus in M-mode averaged 533.4 ms (SD=117.6) with a range of 378.0-742.0 ms for trial one and 513.9 ms (SD=91.0) with a range of 383.0-703.0 ms for trial two.
Table 1
Descriptive Statistics Comparing Measurements between Trial One and Trial Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Measurement (cm)</td>
<td>21</td>
<td>3.262</td>
<td>0.575</td>
<td>1.900</td>
<td>3.170</td>
<td>4.240</td>
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<td>B-mode Dry Swallow Trial 1 (cm)</td>
<td>21</td>
<td>1.119</td>
<td>0.470</td>
<td>0.090</td>
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<td>2.120</td>
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<td>1.1095</td>
<td>0.4295</td>
<td>0.490</td>
<td>1.030</td>
<td>2.240</td>
</tr>
<tr>
<td>B-mode 5.0 cc bolus Trial 1 (cm)</td>
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<td>1.256</td>
<td>0.540</td>
<td>0.580</td>
<td>1.180</td>
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<tr>
<td>M-mode 2.5 cc bolus Trial 1 (ms)</td>
<td>19</td>
<td>480.2</td>
<td>117.9</td>
<td>313.0</td>
<td>469.0</td>
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<tr>
<td>M-mode 5.0 cc bolus Trial 1 (ms)</td>
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<td>117.6</td>
<td>378.0</td>
<td>508.0</td>
<td>742.0</td>
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<tr>
<td>B-mode Dry Swallow Trial 2 (cm)</td>
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</tbody>
</table>
### Research Question 2: Can ultrasonic measurements be duplicated across examiners?

Results indicated that two measurements (B-mode, 2.5 cc bolus and M-mode, 2.5 cc bolus) demonstrated a highly significant positive correlation between the two individuals performing ultrasound measurements (p-value = 0.002 and p-value = 0.0285). Both B-mode dry swallow and M-mode 5.0 cc bolus measurements exhibited marginally significant positive correlations between trials one and two (p-values 0.0885 and 0.052, respectively). The Pearson correlation of B-mode 5.0 cc revealed a weak negative correlation between trial one and trial two (p-value 0.207). P-values were divided by 2 in order to check for only a positive correlation.

#### Table 2
Correlations of Measurements taken between Trial One and Trial Two

<table>
<thead>
<tr>
<th></th>
<th>Pearson Correlation</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Mode Dry Swallow</td>
<td>0.314</td>
<td>0.177</td>
</tr>
<tr>
<td>B-Mode 2.5 cc</td>
<td>0.629</td>
<td>0.004 *</td>
</tr>
<tr>
<td>B-Mode 5.0 cc</td>
<td>-0.199</td>
<td>0.414</td>
</tr>
<tr>
<td>M-Mode 2.5 cc</td>
<td>0.443</td>
<td>0.057</td>
</tr>
<tr>
<td>M-Mode 5.0 cc</td>
<td>0.385</td>
<td>0.104</td>
</tr>
</tbody>
</table>

* denotes p < .05 level of significance
Figure 1
Correlations of Trial 1 vs. Trial 2 Assessments

Scatterplots of responses: trial 1 vs 2 assessments
CHAPTER V

Discussion

This study collected ultrasound measurements in time (ms) and distance (cm) of swallows in 3 and 4 year old children. The primary objectives of this study were to (a) determine preliminary normative values for future studies in ultrasonic measurement and (b) determine the inter rater reliability between two trained individuals conducting the measurements.

Normative Data and Inter rater Reliability between Examiners

This study compared measurements of 3 and 4 year old children with differing bolus sizes of 2.5 and 5.0 cc, as well as a dry swallow. Measurements were taken in time (ms) and distance that the hyoid bone moved (cm). Measurements were also taken to determine the distance between the child’s hyoid bone and mandible at rest. Mean measurements, standard deviations and ranges on the subjects of this study have been provided. There was a wide variability in the measures collected, indicating individual variances between kids. These variances may have been as a result in anatomical differences (i.e. distance between mandible and hyoid bone) and individual variances in habitual eating habits. For example, some kids proceeded to swallow the bolus quickly, whereas others slowly propelled the bolus posteriorly and/or swallowed more than once. This study was successful in the collection of these figures, and will provide a basis for future studies of this nature.

The present study also examined the inter rater reliability between two trained individuals conducting the ultrasound measurements. Results indicated that there was a positive correlation in 4 out of 5 of the measurements taken (with exception to B-mode, 5.0cc bolus). Only one of the five measurements had a highly significant positive correlation. These results support the need for a higher subject sample for normative data. The number of subjects (N=21) was only one subject above the minimum requirement as determined by a statistician. Additionally, compliance was an issue with 2 of the 21 subjects that participated, and therefore not all measurements were based on all 21 subjects.

Additionally, several children were observed swallowing more than once when presented with a bolus of 5.0 cc. These additional measurements were not calculated in
the results per direction of a statistician. Considering many children potentially swallowed a 5.0cc bolus in segments rather than as one bolus, this could have potentially skewed the results and explained the weak negative correlation.

Considering 4 out of 5 measurements did indicate a positive correlation, it is assumed that acquiring data from additional subjects in addition to the 21 subjects of this study would increase this correlation. A sample of only 20 subjects is not actually a representative sample of the entire population of three and four year old children. Therefore, this study has achieved the goal of laying the foundation for future studies with this population. However, the number of subjects involved is not sufficient enough without additional research and data collection to support this sample of normative data.

Implications of the Study

Research using ultrasound to assess swallowing in three and four year old children is extremely limited, and there is a significant need for additional normative data for this population. The results of this study indicate that there is an overall positive correlation between examiners. The differences between measurements taken may be attributed to individual variances between swallows, specifically relative to swallowing more than once with a 5.0 cc bolus. The only measurement that showed a negative correlation was 5.0 cc in B-mode. This measurement was the last measurement taken in each particular instance of data collection, and therefore may have been affected by the child’s diminishing compliance.

The data collected on the 3 and 4 year old children in this study provides preliminary clinical data in ultrasonic measurements of a swallow. This data in combination with future normative data collection may have implications for professionals assessing young children with dysphagia and provide a means of alternative assessment that is non-invasive and radiation free.

Limitations

An objective of the present study was to establish preliminary normative data for swallowing ability using ultrasound in 3 and 4 year old children. One limitation to this particular objective is the small sample size. Normative data collected from a larger sample would increase accuracy and improve the representation of the population under
investigation. Nevertheless, this current sample did provide a means of preliminary data for professionals to further via collection of a larger sample.

Additional limitations of this study were compliance issues. Lack of compliance depended upon the personality, hunger, and energy level of the child. Measures were obtained in a routinely manner, and it was not uncommon for the child to tire by completion of the first trial. Reinforcement was provided to encourage the child to complete the collection of data. However, this lack of compliance may have altered the accuracy of measurement. Two of the 21 subjects refused to finish collection of data, even after consistent reinforcement, and therefore only 19 of the 21 intended subjects fully participated in the data collection.

Unfortunately, recruitment of subjects also posed limitations, and the incentive was changed through the course of data collection to encourage parents to allow their children to participate. This particular research study was also paired with another study, which posed as a limitation considering additional materials were required for parents to complete than was necessary for the current study. Therefore, possibilities that hindered recruitment may have been lack of time for completion of necessary materials, or no interest in the incentive offered. Future studies would require a more tangible incentive, or more time to allow for a larger sample response.

Another limitation would be with respect to a limited geographic location. Subjects were recruited only from the Greater Cincinnati area. This in addition to the limited sample size indicates a weak representation of the overall population. These regional demographic limitations are indicative of a need for a more diverse sample in the future.

An additional limitation to the diversity of the sample includes the fact that all data collected were based upon Caucasian students. Data was collected from preschools of primarily middle to upper class, and therefore this sample is not necessarily representative of all socioeconomic levels. A broader representation of cultural groups is necessary for a representative sample of the population.

*Future Research*

Given the results of the current study, future research should continue to collect normative data using ultrasound as a means to assess swallowing function in children.
The present study focused on subjects in the Greater Cincinnati area. Collection of a more representative sample should ideally include factors such as socioeconomic status, cultural diversity, and geographic location. A future path of investigation would be to gather a larger sample size more representative of current demographic trends, and to compare the results with the outcome of this present study. Effects that compliance has on measurement accuracy should also be explored further.

With respects to inter rater reliability, future studies should ensure that both examiners have parallel experience using ultrasound measurement, possibly via a more standardized method of training. In the current study, the examiner conducting the measurements of trial one had more experience conducting ultrasound than the examiner conducting trial two. Although this experience was not a vast difference, it may have had an impact upon accuracy of measurements, particularly when compliance with the child was sometimes difficult at conclusion of trial two.

More extensive studies of this nature will be necessary to investigate if the findings of this research indeed can be generalized to all 3 and 4 year old children. Similarly, a larger population sample will supplement this overall purpose of normative data. Diversity of the population representative of the current U.S. census data should also be considered for an accurate representation.

A future question relative to this research would include determining what size of a bolus is more appropriate to instigate only a single swallow. As previously discussed, many children were observed to swallow twice when presented with a 5.0cc bolus of pureed food. Future studies should focus upon determining what bolus size (i.e. 3.0cc or 4.0cc) would be more appropriate to elicit a single swallow, and thus show a more consistent positive correlation amongst examiners. Using this method, as well as improvement upon standardized training protocol of use of the ultrasound should provide more consistent results as using ultrasonography as an assessment tool.
REFERENCES


National Institute of Neurological Disorders & Stroke. (n.d.). NINDS Muscular


