MEASURES OF HYOLARYNGEAL EXCURSION IN POST STROKE SURVIVORS FOR DIFFERENT BOLUS VOLUMES AND VISCOSITIES

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MAY, 2019

MYSURU

CERTIFICATE

This is to certify that this dissertation entitled "**Measures of Hyolaryngeal Excursion in Post Stroke Survivors for Different Bolus Volumes and Viscosities"** is a bonafide work submitted in part of fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number **17SLP016.** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled "**Measures of Hyolaryngeal Excursion in Post Stroke Survivors for Different Bolus Volumes and Viscosities"** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Measures of Hyolaryngeal Excursion in Post Stroke Survivors for Different Bolus Volumes and Viscosities"** is the result of my own study under the guidance of Dr.Swapna.N, Associate Professor of Speech Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

May, 2019

Registration No. 17SLP016

DEDICATED TO MY

MY DEAREST PAPAJI, TO HAVE ALWAYS BELIEVED IN ME (I MISS YOU)

MY LOVELY MUMMYJI, REASON FOR WHO I AM TODAY

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BELIEVE IN URSELF, STAY STRONG AND CHASE UR DREAMS COZ LIFE IS WHAT U MAKE IT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Stroke is a life-threatening serious medical condition that arises when the blood supply is cut off or reduced to the brain, which directly influences its cells, resulting in its death. This occurs either when the artery is blocked (ischemic stroke) or the blood vessel leaks or bursts (hemorrhagic stroke). Several high risk factors are associated with stroke such as unhealthy lifestyle, habits like smoking and drinking, heart disorders, gender, hypertension, obesity etc. Elderly individuals above 50 years have the greatest risk of acquiring a stroke.

Stroke is found to be second most widespread source of death and disability worldwide, affecting around 15 million people each year (Townsend, et al., 2012; World Heart Federation, 2016). Based on the American Heart Association's Heart Disease and Stroke Statistics 2012 Update, annually 795,000 people are affected either by a new stroke or by a recurrent stroke (Roger, Go, Lloyd-Jones, &....... Fullerton, 2012). Among the different types of strokes, 87% are reported to be ischemic and 10% are found to be intra-cerebral hemorrhagic strokes, while only 3% comprises of the subarachnoid haemorrhage strokes. In India, the incidence of stroke is much higher than Western industrialized countries. The estimated adjusted prevalence rate of stroke range from 84-262/1,00,000 in rural and 334-424/1,00,000 in urban areas. The incidence rate is 119-145/100,000 as per a recent population based investigation (Pandian & Sudhan, 2013).

Stroke is found to be one of the major sources of serious physical and linguistic disability. It causes physical impairments manifested in the form of hemiplegia, gross and fine motor impairment and visual defects. Linguistic deficits may include impaired comprehension, expression, naming, repetition and reading and writing. In addition, the speech apparatus can also be affected resulting in muteness, dysarthria, or apraxia. Cognitive changes such as impaired memory, confusion, impulsivity, poor executive function and deprived attention are common. Other associated problems in these patients include impaired oral motor function, drooling, hearing impairment, fractures, pain, and swallowing abnormalities. These major changes influence the communication, resulting in social isolation, depression and other negative emotions, affecting their overall quality of life.

One of the difficulties commonly seen immediate post stroke is the feeding and swallowing difficulty. Dysphagia i.e. swallowing difficulties, affect 13–94% of persons with acute stroke, with its incidence depending on the type of stroke, site and size of lesion (Depippo, Holas, Reding, Mandel, & Lesser, 1994; Cook & Kahrilas, 1999; Aydogdu, Ertekin, Tarlaci, Turman, Kiylioglu, & Secil, 2001) and the nature and severity of swallowing problems varying widely with it. Individuals with multiple lesions are at greater risk for developing swallowing abnormalities than those with single lesion. Swallowing problems are found in individuals with unilateral or bilateral brainstem, cortical and sub-cortical strokes (Logemann, Shanahan, Rademaker, Kahrilas, Lazar, & Halper 1993). Typically, patients with an infarct limited to the posterior cortex with no motor component, will not experience swallowing difficulties unless the posterior lesion creates sufficient edema to affect the anterior cortex. Not just swallowing difficulties but, stroke patients are at risk for malnutrition, lung infection, aspiration, pneumonia, and dehydration secondary to dysphagia.

Individuals with stroke may have difficulties in all phases of swallowing including oral, pharyngeal and esophageal phases. Even if either of the stages alongside the pathway is damaged or interspersed, the successive phases are also detrimentally affected. The swallowing abnormalities in stroke are numerous and may include oral lateral sulci retention, delayed oral transport, impaired or delayed swallow initiation, delayed elicitation of a pharyngeal swallow, poor movement or increased activity of suprahyoid and infrahyoid muscles, decreased elevation of hyolarynx, slowed movement of larynx, reduced UES opening and risk of aspiration (Logemann, 1998). Research has also reported that the pharyngeal transit time is increased or could be decreased in post stroke individuals. A study by Aviv and colleagues (1996) indicated that dysphasic stroke patients exhibit reduced pharyngeal and supraglottic sensation when juxtaposed with age -matched normal controls.

In most of the recent studies, the primary focus has mostly been the pharyngeal phase of swallowing. The pharyngeal phase is complex involving twenty different muscles and skeletal constituents. One of the vital events of this phase is the elevation of the hyolaryngeal structure. This structure comprises of hyoid bone, larynx, and other associated skeletal structures and musculature. Studies have reported that hyoid and larynx are closely related to each other. The hyolaryngeal complex directly connects the pharynx with both the trachea and the esophagus. This structure displaces the larynx anteriorly away from the trajectory of the forthcoming bolus and outstretches the upper esophageal sphincter (Khosh & Krespi, 1997; Matsuo & Palmer, 2008; Okuda, Abe, Kim, Agematsu, Mitarashi, Tamatsu, & Ide, 2008). This complex is crucial as it is a protective mechanism of swallowing.

Minimized elevation of hyolaryngeal complex and bad timing of anatomical movements are commonly associated with aspiration in post-stroke patients (Martino, Foley, Bhogal, Diamant, Speechley, & Teasell, 2005), which is indicated via the extent and rate of the excursion in the superior and anterior directions. Hence, hyolaryngeal complex and its movements have been extensively studied in post-stroke individuals using objective and subjective measures of evaluation.

Studies have reported a reduced hyoid elevation (Perlman, Booth, & Grayhack, 1994; Van der Kruis, Baijens, Speyer, & Zwijnenberg, 2011), reduced vertical excursion of hyoid bone (Perlman, Booth, & Grayhack, 1994; Steele & Miller, 2010), which further suggests a reduced elevation of laryngeal complex (Kuhl, Eicke, Dieterich, & Urban, 2003). This reduction may lead to aspiration as hyoid and larynx move together as a complex (Li, Hori, Minagi, &..... Maeda, 2013) and causes incomplete closure of airway, as there is loss of the protection to the pathway or decreased velocity in contraction of the muscles intricated in elevation of hyolarynx (Zhang Zhou, Wei, Yang, Wang, Zhou, & Villegas, 2016). Kahrilas, Lin, Rademaker, and Logemann (1997) using VFSS found a delayed initiation and slow movement of deglutitive laryngeal elevation which was proportional to the severity of swallow dysfunction in stroke individuals.

On the same lines, Hans, Shin, Jun, Park, Ko, Choi, and Kim (2016) also found that the hyolaryngeal elevation was reduced in 88% of stroke survivors with aspiration, indicating less protection to the airway path or diminished upper oesophageal sphincter opening during the pharyngeal phase of swallowing. However it was also found that in post stroke survivors with no penetration or aspiration, only 37% showed limited hyolaryngeal elevation.

However there are studies which also indicate no differences in the hyolaryngeal excursion in the post stroke survivors and the healthy controls. Researchers (Kim & McCullough, 2009; Oommen, Kim, & McCullough, 2010) have also looked into the swallow of individuals with stroke by dividing them into aspirators and non aspirators. There was no significant difference in the elevation of larynx superiorly in the aspirator and non-aspirator group of stroke individuals. In general, both the groups had greater maximum vertical displacement than the anterior displacement.

Paik, Kim, Lee, Jeon, Lim, and Han (2008) also found that there was no significant difference in the hyolaryngeal excursion in post stroke patients, though the displacement pattern had multiple peaks and concluded that the movement of hyoid bone extent and pattern varies with the aetiology of swallowing dysfunction.

Swallowing is also known to be biomechanically modified by volume, texture, taste, method of delivery, age, taste, consistency and many other factors. These factors can directly or indirectly influence the swallowing mechanics. These modifications in the diet are frequently used for the specific management of individuals with dysphagia. However the results of these studies are not uniform due to subject variability, type of swallowing instrument used for assessment, bolus type, and number of swallow tested. Among the various factors which modify the swallowing, most of the studies have tried to modify bolus volumes and viscosities and have studied their effect in neurotypical individuals and in individuals post stroke.

Increasing the volume of bolus will automatically increase the bolus transit time, as it is observed by sustained laryngeal elevation and hyoid excursion. In addition, when the volume of the bolus is larger, the duration of laryngeal closure and

UES opening is increased, but a decreased duration of tongue base contact to posterior pharyngeal wall is also observed (Bisch Logemann, Rademaker, Kahrilas, & Lazarus, 1994; Kahrilas, Lin, Logemann, Ergun, & Facchini, 1993; Lazarus Logemann, Rademaker, &..... Halper, 1993).

Physiologically, many studies have proved that when the bolus viscosity is increased, it results in an increase in lingual-palatal contact pressure, pharyngeal pressure and upper esophageal sphincter relaxation and reduced speed of bolus transit (Dantas, Dodds, Massey & Kern, 1989; Pouderoux & Kahrilas, 1995; Chi-Fishman & Sonies, 2002; Butler, Stuart, Castell, Russell, Koch, & Kemp, 2009).

In specific to hyolaryngeal mechanics, various studies have reported changes in its mechanism in support of changing the bolus volumes and bolus viscosity. Dantas, Kern, Massey, Dodds, Kahrilas, Brasseur, and Lang (1990) in a VFSS study and Chi-Fishman and Sonies (2002) by employing ultrasonography found larger anterior laryngeal movement and UES opening, greater maximal amplitudes of hyoid movement in healthy individuals with the increase of bolus volume from 2mL to 30mL. Chi-Fishman and Sonies, (2002) reported greater total duration of movement of hyoid and peak to peak velocities of movement of hyoid which was also found to be larger for nectar thick liquids and thin liquid but not for ultra thin liquid. Similar results using VFSS were found by Nagy, Molfenter, Péladeau-Pigeon, Stokely, & Steele (2014). Nascimento, Cassiani, Santos, and Dantas (2014) using video fluoroscopy found that there was no significant difference observed with bolus volume or viscosity in the association between pharyngeal clearance duration and hyoid movement duration.

A few studies conducted on individuals post stroke for different bolus volumes and bolus viscosities have reported that there was an increased duration of hyoid elevation between stroke survivors and the normal individuals (Bisch et al., 1994; Chi-Fishman & Sonies, 2002; Wu, Chu, Liu &.... Li, 2018). On the contrary, studies (Kahrilas, Lin, Rademaker, and Logemann, 1997; Paik et al., 2009; Choi, Ryu, Kim, Kang, & Yoo, 2011; Hans et al., 2016; Zhang et al., 2016) have also found that there was reduced hyolaryngeal elevation in post stroke individuals, which could be leading to higher risk of aspiration due to incomplete airway closure. Other studies (Clave´ et al., 2013; Rofes, Arreola, Mukherjee, Swanson, & Clavé, 2014; Nascimento, Cassiani, Santos, & Dantas., 2015) did not find any significant difference by increasing bolus viscosity and changing the bolus volume on the durational aspects of swallow. Thus there is a need to for further investigation as there are limited conclusive evidences.

Need for the Study

Swallowing is an important part of daily life and with the high prevalence of dysphagia in stroke, the assessment and management of dysphagia is very crucial. One of the important events that occur in the pharyngeal phase is the hyolaryngeal excursion. Hyolaryngeal elevation is a core mechanism for protection from aspiration. Mistiming of the various movements of the structures and also the reduced hyolaryngeal elevation are risk factors that are known to be associated with aspiration in post-stroke survivors.

There are heterogeneous group of diagnostic procedures that exist for assessment of hyolaryngeal elevation, yet all have their own limitations. Most of the studies have either used Video fluoroscopy (VFSS), Ultrasonography (USG) or

Fiberoptic endoscopic evaluation of swallowing (FEES) to analyze the different amplitude and durational aspects of hyolaryngeal elevation. Some studies have looked into the effect between the bolus volumes and bolus viscosities on hyolaryngeal elevation in stroke and neurotypical individuals.

VFSS is an instrumental assessment of swallowing and involves the use of radiological contrast agent such as barium to swallow when mixed with a bolus. Radiology suite is required during testing, and a number of hands are required to help and it is expensive. Though VFSS is reliable and efficient, it is not readily available to all the clinicians. In FEES, a flexible laryngoscope is passed trans-nasally until the hypo-pharynx so that the larynx and pharynx are visualized. Food and various consistencies of drinks have to be dyed to aid in bolus visualization. Ultrasound uses high-frequency sound waves (2-10 MHz) and receives the echoes which are then converted to real time images. In this the quality of images and interpretation depends on the operator and the soft areas behind hyoid and larynx cannot be visualized. Though, VFSS and FEES are gold standard tests for the diagnosis of dysphagia (Lowery, 2001), these require specialist staff and equipment, are invasive, expensive and exposes the patient to radiation. Also, there is still a lack of consensus using the various instruments regarding the aspects of swallowing and hyolaryngeal movement. Hence non invasive assessment procedures, such as accelerometry needs to be explored as a prospective approach to assess hyolaryngeal elevation.

Accelerometry is a non-invasive procedure used to determine the physiological vibration signals. The sensors are placed on the subject’s neck superficially at the level of the cricoid cartilage. Reddy, Canilang, Casterline, Rane, Joshi, Thomas, and Candadai (1991) proposed that the digital processing of swallowing accelerometry signals would allow quantitative evaluation of the resulting acceleration measurements, which might be capable of distinguishing healthy and abnormal swallows as they record the epidermal vibration signals of the swallowing process at that surface. Accelerometry signals which are detected at the surface of the skin can be explained by the movements of the hyoid bone and the larynx during swallowing.

Reddy and colleagues (2000) used a single-axis accelerometer to show the relationship between the accelerometric signal and laryngeal elevation during swallowing. Single-axis swallowing accelerometry has shown potential as a non-invasive clinical swallowing assessment tool. Their results showed a significant correlation between the peak elevation of larynx and the maximum magnitude of the acceleration signal.

The advantages of using an accelerometer for dysphagia assessment and management include its low cost, easy portability, good reliability, and simplicity. Accelerometry is relatively easy, less time consuming and requires minimal response from the patient. Accelerometry has been gaining importance in the research from past few years, but its use in a clinical setting, as diagnostic and screening tool is only explored recently. This, at present is a quick effective screening tool being tried to be explored in the recent past for detection of aspiration. This, unlike VFSS does not expose the patients to any kind of harmful radiation. Furthermore, this is non-invasive and a cost effective protocol. This can act as alternative to other methods of evaluation and can also be used in therapeutic management of dysphagia. On the other hand, the principle of how the accelerometry signals are produced and the underlying physiology of these movements are not understood completely.

Understanding and investigating the usage of the accelerometry signals would be a great asset for the research. There are a very few studies that have been conducted using the accelerometric principles. Also, a detailed review into the existing literature revealed that the working of accelerometry by measuring the hyolaryngeal structure in neurotypical individuals and the stroke individuals is rarely investigated. Currently, there are limited studies that have examined quantitatively, the complete temporal trajectory of the hyoid bone relative to the evolution of the accelerometry signals.

The investigations on bolus volumes and viscosities are necessary as dietary modifications are recommended to post stroke survivors, in terms of changing the amount, texture and quantity of food given to them and also the consistency of the food introduced. Patients can benefit by modifying the texture of foods. Changing the volume i.e. when the volume of bolus is increased or viscosity of liquids is changed, it is found to reduce dysphagia symptoms for some patients. This change can directly affect the different aspects of swallowing. Using Video fluoroscopy (Kuhlemeier, Palmer, & Rosenberg, 2001; Clave De Kraa, Arreola, Girvent, Farre, Palomera, & Serra-Prat, 2006; Choi, Ryu, Kim, Kang, & Yoo, 2011; Leonard, White, McKenzie, & Belafsky, 2014; Rofes et al., 2014) and Fiberoptic endoscopic evaluation of swallowing (Diniz, Vanin, Xavier, & Parente, 2009; Leder, Judson, Sliwinski, & Madson, 2013) various authors have found that when high viscous boluses were introduced in contrast to thin boluses for stroke individuals a significant reduction in prevalence of aspiration was observed. Studies (Bisch et al., 1994; Inamoto et al., 2013) have reported that using thickening agents is beneficial in post stroke survivors as it decreases the velocity of bolus, and increases the duration of swallow in comparison to thin liquid. Thickeners are usually used for those who demonstrate poor oral control of liquids and have reduced airway protection.

Although it is known that swallowing can be modified physiologically by the type of food or liquid (i.e., stimuli) consumed, the effects of these various stimuli on accelerometry signals have never been meticulously explored. While the normal sequence of various anatomical gestures in swallowing is well documented, a focus has never been placed on the anatomical motion of the tiny structures, like those of the hyoid bone and laryngeal complex, and also in relation to each other. There is very little research that has been carried out to quantify the hyolaryngeal elevation in combination with the different types of bolus based on viscosities and the volume of bolus used.

Keeping this in view, the current study was planned to investigate the hyolaryngeal excursion using accelerometry signal characteristics to measure the amplitude of the hyolaryngeal elevation and the duration of same. The effect of different bolus volumes and viscosities on the hyolarynx complex and how it differs in neurotypical individuals when compared to neurological conditions, particularly in post stroke survivors, using accelerometry has rarely been investigated. Hence, the current study was undertaken.

Aim of the study

The aim of the existing study was to investigate the hyolaryngeal elevation in post stroke survivors. The specific objectives of the study were

- To investigate the duration of hyolaryngeal excursion during the swallow of two different bolus volumes and viscosities in post stroke survivors and compare it with the neurotypical individuals.
- To assess the amplitude of hyolaryngeal excursion during the swallow of two different bolus volumes and viscosities in post stroke survivors and compare it with the neurotypical individuals.

CHAPTER II

REVIEW OF LITERATURE

Swallowing is a complex process where the food has to be propelled from the oral cavity into the pharyngeal cavity and finally into the oesophagus to be delivered into the stomach for digestion. It ensures that the body is hydrated and healthy by transporting external fluids and nutrients into the body. This process of swallowing is very complex, involving actions which are well coordinated between different systems like the neurological, respiratory, articulatory and gastrointestinal systems. The visceral, somatic, afferent and efferent nerves have to be well coordinated with the associated striated and smooth muscles. The action of the structures common to swallowing, phonation and respiration such as the mouth, larynx, pharynx and upper esophagus must be coordinated to result in a healthy swallow.

Phases of swallow

Logemann (1988) established the four stage model to describe the act of swallowing, where each stage is independent involving the voluntary oral preparatory and oral transit phases, and the involuntary pharyngeal and esophageal phases. Studies based on the four stage model adequately describe biomechanics and bolus movement during command swallow of liquids (Dodds, 1989; Logemann, 2007).

Oral phase

It consists of the muscular events responsible for the movement of bolus from the tongue to the pharynx. The oral stage is divided into oral preparatory and oral transit/propulsive stages.

Oral preparatory phase

This phase begins with the ingestion of bolus into the oral cavity, where the bolus is displaced and transferred by the tongue and lateral movements of mandible with the crushing action of the upper and lower teeth. From the time the food is introduced to mouth, seal at the lips is sustained to ensure the food does not fall out of the mouth. The salivary glands secrete the saliva which helps not only in the formation of bolus, but also aids in digestion that begins in the oral cavity. The food is moved posteriorly at the molars to be chewed properly which results in proper mastication of food. The cycle is repeated numerous times before forming a bolus and initiating the oral phase of swallow. The bolus is then held between the tongue and hard palate before the initiation of voluntary swallow. The larynx and pharynx are at rest. The airway is open and nasal breathing continues until a swallow is produced. By the end of this phase, the tongue tip rests on the maxillary alveolar ridge and the material is manipulated into a cohesive bolus compressed by the tongue against the hard palate (Dodds, 1989; Ertekin & Aydogdu, 2003; Logemann, 2007).

Oral propulsive phase

This phase is a voluntary phase, which begins once the bolus is properly prepared with the posterior propulsion of the food bolus by the tongue and ends with the production of a swallow. The initiation of a swallow of a bolus of food or liquid is under voluntary control, although the final stages of the swallow process are involuntary. The voluntary actions in manipulating a bolus of food or liquid include the elevation of the tongue followed by a posteriorly directed movement resulting in a peristaltic motion. At the start of the transfer phase, the tongue movement during this oral phase has often been described as a stripping action. This is caused when the midline of the tongue in a sequence, squeeze the bolus posteriorly against the hard palate. The sides and tip of the tongue remain resistant against the alveolar ridge. During this time, a central groove is formed in the tongue, acting as a ramp or chute for food to pass through as it moves posteriorly which propels the bolus into the oro-pharynx (Ramsey, Watson, Gramiak, & Weinberg, 1955). The transfer phase is completed when the bolus tail enters the oro-pharynx. Elevation of the soft palate occurs against the posterior pharyngeal wall and at the same time the nasopharynx is sealed off to prevent nasopharyngeal reflux (regurgitation), to allow the bolus entry to the pharynx (Dodds, 1989). Finally, the bolus leaves the oral cavity.

Pharyngeal phase

This phase also known as swallowing reflex, is the shortest, involuntary and complex phase of swallowing, as it depends on the consistency of the bolus, size of bolus and single or multiple event of swallow. The pharyngeal transit time is normally 1 second or less. This phase mainly has two events; transport of the bolus from the oral cavity to the oesophagus and protection of the airway. At the onset of the swallowing in this phase, tongue forces the bolus through the pharynx, as the pharyngeal constrictor muscles contract to guide the bolus from oro-pharynx. This phase involves interaction of nasal, laryngeal and tracheal airway for safe swallow and involves complex interaction of velopharynx and larynx characterised by velopharyngeal closure. The anterior, superior movement of hyoid causes the elevation of larynx, as suprahyoid muscles are contracted. The epiglottis moves down to cover the laryngeal vestibule, thus aids to seal the airway from the pharyngeal cavity. The true and false vocal folds and arytenoids are adducted so as to close the trachea. Also, there is progressive pharyngeal contraction and opening of the upper esophageal sphincter (UES). All these actions are to protect the airway from food penetration.

Oesophageal phase

This phase begins when the bolus enters the esophagus at the cricopharyngeal juncture or UES. This sphincter opens by forces of traction on the anterior wall exerted by contraction of the suprahyoid and infrahyoid muscles. The peristaltic wave, which begins at the top of the esophagus, pushes the bolus ahead of it and continues in sequential fashion through the esophagus until the lower esophageal sphincter (LES) opens to allow the bolus to enter the stomach. The LES, which is closed at rest, relaxes during deglutition to allow the passage of esophageal contents into the stomach. The LES provides a barrier against reflux of gastric contents into the esophagus (Fisher, Malmud, Roberts, & Lobis, 1977). Normally the transit time at the esophageal level varies from 8 to 20 seconds (Dodds, Hogan, Reid, Stewart, & Arndorfer, 1973). Relaxation of the LES for the same occurs within 2 seconds of swallowing and persists for approximately 8-10 seconds.

Neuromuscular Control during Swallowing

Swallowing is controlled and coordinated through specific regions in the cerebral cortex and brainstem. The neural control of swallowing involves the cortical and sub-cortical structures.

Cortical control

The cortex has higher order control over the swallowing mechanism, including a primary role in the voluntary initiation of swallowing and it is largely under bilateral cortical control. During the oral phase of swallow, the caudolateral sensorimotor cortex is responsible for initiation of swallowing (Hamdy, Rothwell, Aziz, & Thompson, 2000). The primary sensorimotor cortices together with sensorimotor integration areas (BA 5, 7) and primary motor cortex (BA 4) appear to have role in planning and processing volitional swallowing. For the process of mastication, it sends sensory information which stimulates activity in the insula, amygdala and orbitofrontal cortex. The lateral pericentral cortex, fronto-parietal operculum and anterior cingulate cortex areas are responsible for the movements of tongue. In the pharyngeal phase of swallowing, the anterior posterior insula has been consistently activated as reported in imaging studies (Furlong, Hobson, Aziz,.... & Hamdy, 2004). In a magneto-encephalography study reported that during the motor phase of swallowing, the caudal region of the pericentral gyrus and regions of the sensorimotor cortex were also activated. The superior premotor cortex also seems to be involved in the motor phase.

The oral preparatory stage of swallowing is subject to voluntary control through the primary motor cortices, however, the primary motor areas do not appear to be involved during the patterned movements of the pharyngeal stage (Huckabee, Deecke, Cannito, Gould, & Mayr 2003). Pharyngeal movements are influenced by more disseminated indirect pathways connecting cortical motor planning areas to the brainstem motor neurons. The esophageal phase of deglutition is also reflexive and is triggered by bolus stimulation at the proximal esophagus. Cortical activations were seen during swallowing in the sensory and motor cortex, insula and putamen.

The cortex has higher order control over the swallowing mechanism, including a primary role in the voluntary initiation of swallowing, which is largely under bilateral cortical control. The supranuclear areas capable of eliciting voluntary swallowing are located in the frontal motor cortices of both hemispheres, anterior to the sensorimotor cortex (Jean & Car, 1979). The higher brain regions of the cortex have capability to signal to central pattern generator (CPG) to initiate the voluntarily control of swallow and exert the control over the subcortical structures.

Subcortical control

Basal ganglia plays a vital role in a variety of motor, cognitive, and limbic functions by integrating the information derived from multiple cortical regions and conveying it back to frontal cortical regions and brainstem nuclei after processing it. It is a very important component of efferent system in the sensory motor control of swallowing. They function to modulate cortical and cerebellar output for motor control.

The thalamus acts as a sensory-relay station and conveys information about the sensation of eating and swallowing to other cortical and subcortical structures. Both voluntary and involuntary movements happening during ingestion are further modified by the feedback received from kinesthetic images and other afferents converging onto the basal ganglia, which further monitors and refines the movement progression in order to ensure the temporal and spatial accuracy.

The cerebellum is located in the posterior fossa. It attaches to the brainstem with the help of superior, middle, and inferior cerebellar peduncles, which contain the input and output fibers of the cerebellum. Its main function is to integrate massive sensory and other inputs from many regions of the brain and spinal cord, which is used by the cerebellum to smoothly coordinate ongoing movements and to participate in motor planning. Cerebellum does not have direct connections to lower motor neurons, but it has connections to the cortex via the motor system and brainstem.

The brainstem houses the motor and sensory nuclei of the cranial nerves such as trigeminal (V), facial (VII), glossopharyngeal (IX), vagus (X) and hypoglossal (XII), their pathways, and associated brain stem nuclei, whose distribution blankets the oral and pharyngeal passageways. Brainstem structures forming the swallowing pattern generator (SPG) are intimately associated with the nucleus tractus solitarius (NTS). The NTS contains the second-order sensory neurons as well as the pattern-generating circuitry of both the pharyngeal and esophageal phases of swallowing and exhibit a sequential firing pattern which parallels the sequential motor patterns of deglutition (Jean, 1972; 1990). Pons contains motor nuclei of the trigeminal and facial cranial nerves. They are very important for swallowing function. The descending reticular nuclei in the midbrain are involved in reflexive behavior such as coughing, chewing, swallowing and vomiting. Medulla contains the nucleus ambiguous and the dorsal motor nucleus contains the motor neurons of the pharyngeal and esophageal phases of swallowing. Once the oropharyngeal swallowing phase is complete, afferent fibres in the pharynx trigger motor nuclei in the nucleus ambiguous to initiate the peristaltic muscular contractions in the distal pharynx and proximal esophagus that comprise the esophageal swallowing phase (Schindler & Kelly, 2002). Central nervous unit is located in pons and medulla which is referred to as brainstem's CPG for swallowing and controls the entire oropharyngeal swallow. CPG coordinates the contraction of 25 pairs of muscles in the oropharynx, larynx and oesophagus. These collections of neurons contain the neural circuitry needed to generate some fundamental rhythmic and repetitive movements such as swallowing, mastication, respiration and locomotion (Jean, Amri, & Calas, 1983; Amri, Car, & Jean, 1984; Amri, & Car, 1988; Amri, Car, & Roman, 1990)

Table 2.1:

Neural regions associated with swallowing function

Region	Hypothesized role
Primary somatosensory, motor and Motor supplementary cortices (BA 1, 2, 3, 4 and 6)	Cortical processing of swallowing, including motor regulation and execution and motor control.
Anterior cingulated area (BA 24 and 32)	Higher order motor processing: swallowing movement planning and execution Cognitive perceptual processes such as attention and response selection.
Orbitofrontal cortex (BA 10,11,12,44,45, and 47)	Unclear
Parieto-occipital cortex (BA 7, 17, 18, 40)	Sensory processing of swallowing Task cue processing, not swallowing per se Movement planning and execution
Temporopolar cortex (BA 22 and 38)	Unclear
Insular cortex	Processing of gustatory input Intraoral sensory modulation
Internal capsule	Functional connection of cortical and brainstem nuclei via corticobulbar tracts
Thalamus	Sensory and motor input processing via thalamocortical and thalmostriatal pathways
Basal ganglia	Gating of sensory input

Cerebral peduncle	Descending pathways from the cortex
Brainstem	Central pattern generator, swallowing regulation
Cerebellum	Regulation of adaptive coordination, sequencing timing, learning and memory of motion

Note: Adapted from McFarland, D. H. (2014). *Netter's Atlas of Anatomy for Speech, Swallowing, and Hearing-E-Book*. Elsevier Health Sciences.

Cranial nerve control of swallow

The various cortical and subcortical structures are responsible for the voluntary control of swallow initiation in the oral phase and the involuntary control of pharyngeal and esophageal phases of swallowing. The pharyngeal and esophageal phases are under neuromuscular control of brainstem. The brainstem houses the various cranial nerve nuclei. These cranial nerves along with the swallowing center in the medulla operate appropriately for the reflexive swallow to occur. The cranial nerves V, VII, IX, X, XI and XII are important and critical for the swallow. Among these cranial nerves a few are motor, a few sensory and a few have mixed nature. The motor components innervate muscles, while sensory components send sensory feedback to brain.

The motor portion of facial nerve (VII) deals with facial expressions and pulling the larynx up and back. *The motor component of the glossopharyngeal nerve (IX),* along with the vagus nerve, innervates the stylophayngeus muscles, which elevates the larynx and pulls it forward during the pharyngeal stage of the swallow. This action also aids in relaxation and opening of the cricopharyngeus muscle. The vagus nerve (X) abducts the vocal folds to protect the airway during a swallow. The sensory component of vagus carries sensory information from the velum, the larynx. External branch of superior laryngeal nerve (SLN) joins with RLN in function, to enhance the swallowing through various innervations to the muscle while the internal branch of SLN carries sensory information from larynx. Recurrent laryngeal nerve (RLN) helps in adduction of vocal fold during swallowing i.e. airway protection and control of upper esophageal sphincter relaxation during swallow to prevent refluxed material from entering the airway.

Table 2.2:

Overview of the distribution of cranial nerve across the phases of swallowing

Phase of Swallow	Innervations
ORAL PHASE	
Buccinator and orbicularis oris	VII – buccal branch
Lip sphincter and other face muscles	Facial (VII)
Muscles of mastication	Trigeminal (V3) mandibular branch
Tongue – intrinsic muscles	Hypoglossal (XII)
Extrinsic muscles	Ansacervicalis (C1-C2)
Palatoglossus	Vagus (X) and XI
Palatophaaryngeus	Vagus (X) and XI
Post belly digastricus	VII
Geniohyoid	C1 (ansa cervicalis) and XII
PHARYNGEAL PHASE	
Stylopharyngeus	Glossopharyngeal (IX)
Superior and middle pharyngeal constrictor	Vagus (X) and XI
Palate, pharynx, and larynx	Vagus (X)
Tensor veli palatine	Trigeminal (V3-mandibualr)
Levator veli palatine	XI and X
Hyoid and laryngeal movement	V3, VII, C1-C2
ESOPHAGEAL PHASE	
Opening of cricopharyngeus (UES)	VII (primary), V
Peristalsis	Vagus (X)

Note: Adapted from Corbin-Lewis, K., & Liss, J. M. (2014). *Clinical anatomy & physiology of the swallow mechanism*. Nelson Education

Swallowing problems in adults

Swallowing can get affected in adults either due to damage to the peripheral swallow mechanism or due to any damage in the nervous system or the neural pathway which has an effect on swallowing of one's own saliva, liquids, food of all consistencies and pills. The swallowing difficulties manifested in adults can be due to neurogenic or non neurogenic causes. Non neurogenic causes include head and neck cancers, non head and neck cancers, trauma to neck and chest regions, laryngeal injuries, sepsis, laryngeal cartilage injuries, fractures, infections like stomatitis, inflammations like gastro esophgeal reflux disease, esophagitis, chronic obstructive pulmonary disease, structural deficits like achlasia, rings, webs or stenosis. Neurogenic causes include closed head trauma, cervical spinal cord injury Parkinson's disease, muscular dystrophy, multiple sclerosis, amyotrophic lateral sclerosis, Alzheimer's disease, dementia in its severe stages and stroke, surgical complications which can affect the brainstem or cranial nerves, toxins, metabolic dysfunction etc. All these neurological conditions have some or the other phase of swallowing being affected.

All these various types of conditions can result in swallowing abnormalities in one or more stages and some complications. In oral stage, reduction in lateral tongue motion, failure to initiate swallow, failure to push food from front of mouth, drooling, failure to clear residue after the swallow are seen. At the pharyngeal stage, there are residues in the valleculae or in the pyriform sinuses or in the aryepiglotic folds or the posterior pharyngeal wall, decreased hypo-pharyngeal movement, abnormality in UES opening, reduced upward and forward movement of hyoid and diminished velopharyngeal competency are observed. The complications include penetration, aspiration, pneumonia, dehydration, and death in serious cases. These different types of conditions can result in mild to severe swallowing difficulties. One among such conditions is cerebro-vascular accident, commonly known as stroke.

Stroke and its types

Stroke is an interruption in blood supply to any part of brain due to narrowed, blocked, or ruptured arteries. This results in the part of brain being deprived of the oxygen and nutrition, which thus leads to death of brain cells, thus damaging the brain. Strokes are caused by various vascular disorders and depending on the nature of vascular pathology, strokes can be classified as ischemic or hemorrhagic.

Ischemic stroke

This type is caused by vascular disorders that block or interrupt the arterial blood flow to the brain region which results in infarction. Infarction refers to the death of neural tissue (necrosis) which is because of lack of oxygen and caused due to blood deficiency. Ischemic stroke can be either cerebral thrombosis or cerebral embolism.

Embolism is a clot which is carried or keeps moving in the blood stream in the artery as it gets blocked through which it cannot pass. This can sometime also be the broken part of the larger clot of fatty tissue of the artery. Thrombosis involves forming of thrombus where the arteries are completely blocked. These are known to be formed in the larger arteries like the ventricles, internal carotids, basilar than in the smaller arteries. These are usually associated with arteriosclerosis where the inner walls of arteries are damaged by localised deposition of fatty substances and also due to high blood cholesterol levels. Ischemic stroke have greater and faster recovery and the maximum recovery happens in first three months.

Hemorrhagic stroke

These are due to the rupture of blood vessels of the cerebrum, causing bleeding. An artery bursts and blood which is released, damages the brain cells around it by pushing or pulling it. These are usually the aneurysm, which are blood filled balloons (dilations of weak arteries) which easily rupture. This can be an intracerebral haemorrhage rupturing the brainstem or a extra cerebral haemorrhage caused by rupture within the meninges. Usually, this stroke has a slow recovery in all the functions.

Causes of stroke

There are various causes that can result in stroke. The most common causes are abnormally formed blood vessels, high level of blood cholesterol, and hypertension. Individuals with coronary heart disease and those who smoke and drink, are more susceptible to stroke. However, men are found to be more susceptible to suffer from stroke than women. Individuals above 50 years of age are most vulnerable. But stroke in younger age group is also common. There are many risk factors that can result in stroke. Factors related to natural processes like genetics, sex, age and earlier attack of stroke are factors which cannot be controlled medically. Risk factors of lifestyle and environment like diabetes, heart diseases, hypertension, and obesity are those which can be controlled by early medical treatment. In addition, factors like smoking, drinking alcohol, lack of exercise and increased stress, oral contraceptive pills etc. are self controlled risk factors which can result in stroke.

Epidemiology

Stroke is the second most common cause of death and disability worldwide affecting around 15 million people each year (Townsend, 2012; World Heart

Federation, 2016). More than half a million new strokes are reported each year and more than about 2 million people have survived stroke. Stroke causes 11% of total mortality. The incidence of stroke increases with advancing age and is seen more in certain racial groups too. The incidence of strokes in African American men are 50% higher than in white men, while in women it is around 130% higher (Payne, 1997). Whites have higher prevalence of ischemic strokes than Hispanics.

In India, the incidence of stroke is much higher than Western industrialized countries. The stroke is one of the leading causes of serious physical and linguistic disability even if not death. Most of the individuals affected by stroke are usually the elderly individuals of more than 50 years. The estimated adjusted prevalence rate of stroke range from 84-262/1,00,000 in rural and 334-424/1,00,000 in urban areas. The incidence rate is 119-145/100,000 based on the recent population based studies (Pandian & Sudhan, 2013).

Associated changes with stroke

The changes caused due to stroke can be multifaceted. Some of the changes are described below.

Physical changes

Stroke mostly co-exists with notable and distinguishing physical impairments. Common changes include hemianopia which is characterized by blindness in one half of the visual field, stuttering, epilepsy, loss of sensation of pain, pressure, and temperature i.e hemianesthesia. The major physical change which impacts the overall quality of life is the hemiparesis or hemiplegia, i.e., decreased strength or paralysis in one half of the body including the upper and lower limbs usually on the right side. Lower limbs are found to be more affected than the upper limbs. As a result of this, they face problem in walking, dressing, bathing, standing, sitting, writing and many other daily living activities.

This weakness or incoordination is not just restricted to limbs but can also be to the face and muscles of mouth, tongue, pharynx and vocal folds. This weakness will result in dysarthria, apraxia, or dysphagia. The speech of these individuals is slow, laboured, halting and imprecise. They perform poor in speech and non speech tasks.

Behavioural changes

Less obvious changes which are not linguistic in nature include the behavioural changes. These individuals are more prone to these changes as they find it difficult to cope up with the changes happening to them post stroke. They become weak emotionally and are unable to control emotions, exhibiting irritation and annoyed nature. They express emotions to a greater extent much more than before, especially mood swings in terms of fluctuating positive attitude to total despair. They can get easily frustrated, even with small mistakes. Family members usually report of change in the overall personality.

Linguistic changes

Stroke results in aphasia where the different language functions are affected. Chapey (1981) defined aphasia as an acquired impairment of language and cognitive processes which underlie language caused by organic damage to the brain. These linguistic changes can be manifested as one or more language function in terms of reading, writing, speaking or comprehension. Changes seen are based on the type of aphasia that has been caused whether it is fluent aphasia or non fluent type of aphasia.

All stroke individuals exhibit loss of language, seen in spontaneous conversation, narration but that depends on the extent and cause of lesion. Imitation or repetition of single words, phrases or sentences may be entirely lost or marked phonemic paraphasias or omissions are seen. Mild to severe degree of problems in terms of auditory comprehension are seen. They may participate in colloquial conversation, giving verbal replies or by nodding, facial expression or gestures. But they may fail, when standardized tests are used as they aim specifically and not in general. There are also evident naming errors or word finding difficulties known as anomia.

Cognitive changes

Cognitive changes are manifested as confusion regarding time and place, impulsive behaviour, agnosia, spatial perceptual impairment, deficits in self awareness, judgment, inhibition, planning and programming. They have very poor attention and concentration and hence are easily distractible. They find it difficult to attend to tasks, focus during conversation. Even small distractions can make it impossible for them to attend to tasks. Almost all brain injuries are found to impact the memory. Learning something new or trying something different becomes difficult post stroke. They may or may not be able to recall names of family members, places, common items and also with numbers and easy simple calculations. Major difficulty is seen when they have to learn and store new information. Simple tasks like buttoning a shirt, folding clothes, driving may also be forgotten.

Dysphagia post stroke

Dysphagia affects the vast majority of acute stroke patients. Dysphagia is a highly common sequel following stroke, affecting 13–94% of acute stroke sufferers, with incidence relating to lesion size and location (Cook & Kahrilas, 1999; Depippo, Holas, Reding,, Mandel, & Lesser, 1994; Aydogdu et al., 2001). Dysphagia affects more than 50% of stroke survivors (Martino, Foley, Bhogal, Diamant, Speechley, & Teasell, 2005). Fortunately, the majority of these patients recover within 7 days (Smithard, O'Neill, England, Park, Wyatt, Martin, & Morris, 1997). Around 11-13% continues to have swallowing dysfunction at six months (Mann, Hankey, & Cameron, 1999). This represents approximately 80,000 of the 6,65,000 new stroke survivors each year in the US. A more recent study by Martino et al. (2005) reported that more than 50% of post stroke patients encounter dysphagia acutely and the prevalence of oropharyngeal dysphagia following stroke vary between 37% to 78%. Among them the incidence of silent aspiration was also high around 40% - 70%. 20% of stroke persons die of aspiration pneumonia. Smithard, O'Neill, Parks, and Morris (1996) reported that dysphagia identified during bedside clinical examination was associated with an increase of 17% in the incidence of pulmonary infection compared to those who were not dysphagics (33% vs. 16% respectively). Although it improves within 2 weeks for most, some of them face longstanding swallowing problems. A systematic review of research from 1966 to 2005 found that 7% to 29% of reported stroke survivors developed pneumonia as a complication of their swallowing difficulties (Martino, Foley, Bhogal, Diamant, Speechley, & Teasell, 2005).

Aspiration is one of the biggest complications following stroke. Abnormalities in passing of food where the food leads into the airway passage can result in aspiration during, before and after deglutition, which can lead to pneumonia due to immune suppression and poor oral health. Premature spillage of food into the oropharynx and entry of food into the larynx where the larynx fails to close as the swallow of oral phase is not triggered results in aspiration before swallowing. When the larynx fails to close due to weakness or poor coordination of muscles of larynx it results in inter-deglutitive aspiration. Post deglutitive aspiration is when there is poor or abnormal clearance of bolus from hypopharynx results in residue at the entrance of larynx.

Dysphagia is a risk factor for malnutrition, dehydration and is common in those who receive thickened liquids or modified diets. A study reported that 49% of stroke survivors admitted to a rehabilitation unit were malnourished, and that malnutrition was associated with dysphagia (Finestone, Greene-Finestone, Wilson, & Teasell, 1995). Gordon, Hewer, and Wade, (1987) reported that approximately 58% of acute stroke survivors with dysphagia had signs of dehydration (urea concentration of 10 mmol/l or higher) compared to 32% of those that were not dysphagics.

It also increases morbidity and mortality after stroke and predominantly affects quality of life when it is not possible to share meals with family and friends. In a survey by Ekberg, Hamdy, Woisard, Wuttge-Hannig, & Ortega (2002), it was found that after stroke only 45% of them would enjoy eating, while 41% of them experienced anxiety and panic attacks during eating. And in the fear, more than 1/3rd of patients avoided eating with others due of dysphagia.

All these directly impact the discharge of post stroke survivors from hospital. 60% of non-dysphagic patients are discharged home after a stroke while only 21% of patients with dysphagia are discharged. Thus, dysphagia, aspiration and aspiration pneumonia are devastating sequelae of stroke and hence at most care must be taken post stroke.

Mann, Hankey, and Cameron (1999) studied the progress in swallowing in post stroke individuals for over 6 months. 128 patients were included with an acute first stroke. Initial swallowing was assessed at the bedside using Diagnostic Criteria for Clinical and video fluoroscopic assessment of Dysphagia and Aspiration by two speech pathologists and one radiologist. A detailed history was taken regarding the swallowing ability function before and after stroke. An oral motor sensory examination was carried out to assess the various components of swallow, voice, speech and language function. Later the patients were observed in videofluroscopy for the dry swallow and 5mL of water and 20mL and a thickened fluid. There were 112 survivors who were then followed up, and observed over for 6 months for recurrent stroke, any death or chest infections. It was found that swallowing abnormality was detected in 65 patients clinically and in 82 patients using videofluroscopy. At 6 months post stroke, 97 individuals had normal diet like before stroke, while 67 of them had swallowing abnormality seen as penetration of false vocal cords in 34 of them and aspiration in rest of them.

Moon, Yoon, Im Yi, Jeong, and Cho (2017) experimented with 90 patients post stroke. The study aimed to correlate the clinical symptoms and lesions which might result in swallowing issues. 90 haemorrhagic stroke individuals were recruited for the study and were subjected to VFSS. Detailed demographic details including the age, gender, brain lesion laterality, location of lesion and duration of onset of stroke was noted. VFSS was performed with 2mL and 5mL of volume of barium bolus mixed with juice, yogurt, and thick gruel were introduced. Time lapse from the time of first introduction of bolus into the oral cavity to the time bolus reached the mandible at the inferior border level and this represented the oral processing time. For analysis, the data was divided into 2 groups. Patients requiring less than 10 seconds for semi solid food were group I. Group II included individuals requiring more than 10 seconds on the semi solid food. It was found that age, gender, side of lesion, location of lesion, type of stroke did not significantly impact both the groups. However, the scores on Mini mental status examination scores of the Korean version (K-MMSE) were significant between the two groups. K-MMSE was lower for the group with longer oral transit time and vice versa. Thus they concluded that the cognitive aspects can also affect swallow by influencing the oral transit time. The overall oral transit time was delayed. This was attributed to lesion in the frontal lobe which is responsible for planning and execution of movements. This could also be related to the praxis aspect.

Effect of stroke on different phases of swallowing

Stroke can affect any part of brain that controls the various muscles of swallowing, which can affect the swallow. Even if the muscles do not impact directly, it interferes with the motor function and hence affects swallowing. These automatically impact the different phases of swallowing in individuals with stroke. Disorders of the oral and pharyngeal phases of swallowing are very disabling and may place those affected at risk for death from asphyxiation owing to upper airway obstruction by large food bolus. Dysphagia therefore does have prognostic implications and should be assessed in all patients with stroke and at all the various phases of swallowing.

Oral Phase

Functional problems in the oral phase of deglutition include disruption of the preparatory phase, poor bolus control, difficulty in initiating a swallow, and impaired bolus transport.

Preparatory phase: It is manifested as reduction in the ability to mix the bolus and also position the tongue dorsum during swallow. Usually, it is the muscles of tongue, face and jaw that are affected. Hemiplegia, muscle weakness can result in failed ability to position boluses on the surfaces for grinding and also there could be weak grinding forces. Failure to sense the bolus can be due to sensory deficits resulting in poor reduction in bolus and also placement. Failure to initiate mastication can be could be caused due to abnormalities in the higher centres of brain.

Abnormal bolus control: It is the inability or the failure of the oral cavity to maintain the bolus before the swallow can be initiated. This results in anterior spillage of bolus from lips and also early posterior spillage into the pharynx. Here apart from the muscles involved in the preparatory phase, the palatal group of muscles are also involved where there can be muscle action disturbances. Due to sensory deficits, the post stroke individuals may fail to recognize the spillage or even impend it.

Impaired swallow initiation: A lesion in the group of neurons of the brainstem which form the CPG can result in difficulty in the oral phase of swallow initiation. This results in oral manipulation of bolus to an excessive level, bolus accumulation in the oral cavity, or early spillage of bolus into the pharynx. The latter action should trigger a reflexive swallow at the pharynx, but this ability is also lost in these individuals.

Abnormal bolus transport: This occurs due to the difficulty in functioning of the intrinsic and extrinsic tongue muscles. There are repetitive movements of tongue because of which the bolus is not cleared from the oral cavity completely.

Pharyngeal Phase

In the pharyngeal phase, abnormalities are manifested in terms of difficulty in clearing the boluses from the pharynx. This could be because of failure in propulsion of food, obstruction in outflow, or it could be failure to maintain luminal closure at entrance and exit points to the pharynx. There can also be sensory disturbances which prevents the transport of bolus through pharynx due to modification of muscle function. The common problem pertaining to the pharyngeal phase is listed below:

Muscle weakness and incoordination in the pharyngeal phase: Tongue is responsible to provide the necessary force to clear bolus into esophagus, the pharyngeal muscles help to clear the trails of bolus into esophagus from pharynx. Weakness or poor coordination in the contraction of the pharyngeal muscles results in traces of bolus to remain in the pharynx even after the swallow is completed. The weakening of pharyngeal elevators results in long path for the bolus to be transported and the clearance of bolus will be less and poor. Palatal muscle weakness will result in failed attempts of pharynx to seal superiorly, resulting in nasal regurgitation. UES weakness for the reflexive responses will manifest as regurgitation from eso-phagopharynx.

Pharyngeal outflow obstruction: When the bolus has to pass from pharynx to esophagus, it requires the UES to open, which depends on how well the UES relaxes, the movement of suprahyoid and infrahyoid muscles to move the larynx forward, forces transmitted on the incoming bolus and the distension of UES due to its elastic nature. Any abnormality in any of these factors causes impairment in UES opening and clearance of bolus from pharynx.

Laryngeal Phase

Penetration above or to the level of the vocal folds is common, especially for liquids, aspiration is infrequent until the disease progresses to an advanced stage. Aspiration may occur more frequently in those with abnormally rapid pharyngeal movements. Inadequate laryngeal closure during the swallow is increasingly frequent as disease progresses. Silent aspiration may occur but is may be infrequent.

Kahrilas, Lin, Rademaker, and Logemann (1997) investigated 29 patients with stroke in the age range 18-85 years with neurogenic dysphagia with penetration before or during the pharyngeal stage of swallow and compared them with control group of 12 individuals using VFSS. A stepwise regression analysis was used to look into the inadequacy leading to penetration of the bolus into laryngeal vestibule. They measured the duration between the laryngeal vestibule closure and timing of upper oesophageal sphincter relative to glossopalatal junction opening. Their model reported that the severity of laryngeal penetration was around 86% in the dysphagic patients. This was attributed to the delayed initiation and slow movement of deglutitive laryngeal elevation which was proportional to the severity of swallow dysfunction.

Esophageal phase

Most of the studies have focused on the oral and pharyngeal phases of swallowing but its effect on esophageal phase have never been studied extensively and hence, there is less data about the stroke effect on esophageal phase. It is important to determine transit in esophagus in stroke patients because there might be slight alterations in esophageal transit which may contribute to dysphagia.

Weber, Raman, Hannequin, Onnient, Beuret-Blanquart, Mihout and Denis (1991); Aithal, Nylander, Dwarakanath, and Tanner (1999); Micklefield, Jorgensen, Blaeser, Jorg, and Kobberling (1999) found greater number of non-peristaltic contractions alterations to esophageal motility thus, increasing the velocity with which bolus passes the esophagus and increased duration, and velocity of contractions of esophagus (Micklefield, Jorgensen, Blaeser, Jorg & Kobberling, 1999) and this contributed to increased esophageal transit time in stroke patients.

Silva, Fabio and Dantas (2007) found there were alterations in the middle and distal part of esophagus in stroke patients and was characterized by very rapid passage of bolus when compared to normals. Individuals with vertebra-basilar territory infarct had longer duration of middle esophageal transit for liquid bolus, while those with carotid territory infarct had longer duration of esophageal clearance.

Effect of site of lesion on swallow in persons with stroke

There are multiple numbers of areas in the brain which take up different functions in different phases of swallowing. Thus the swallowing problem can vary depending on the site of lesion. Any kind of infarct that occurs in any site of brain can result in swallowing difficulties following stroke, based on the function of that specific site in the central nervous system and the peripheral nervous system. There are various authors who have described about the stroke on various areas of brain and its effect (Barer, 1989; Celifarco, Gerard, Faegenburg, & Burakoff, 1990; Delgado, 1988; Logemann & Kahrilas, 1990; Meadows, 1973; Robbins & Levine, 1988; Smith & Dodd, 1990; Wade & Hewer, 1987).

Effect of Cortical stroke on swallow

The cerebral cortex is a group of neural tissue of the cerebrum, separated by the longitudinal fissure that divides the cerebrum into two equal halves- the right and left cerebral hemispheres. The cortex connects to the subcortical structures to send information along the efferent connections and receive information via afferent connections. The right and left cerebral hemispheres have different function and hence the swallowing functions must also show differences based on the side of the lesion. However, swallowing control in each hemisphere is not yet well defined and dysphagia might be present or just be as a symptom of stroke. Cortical lesions have higher effects on the oral phase of swallow.

Studies have suggested that stroke within anterior left hemisphere of the cerebral cortex may lead to mild to severe degree of swallow apraxia with some degree of oral apraxia too. Swallow apraxia causes delay in oral swallow initiation with no tongue movement when the bolus is presented or by mild to severe searching motions of the tongue prior to the swallow initiation. Individuals are found to be poor when a volitional command is given to swallow and better when they are feeding themselves and eat automatically. Stroke in the left cortex can also result in mild longer oral transit time (3 to 5 seconds) and mild delay in pharyngeal swallow triggering (2 to 3 seconds).

Stroke in the right hemisphere can result in mild oral transit time delays and longer pharyngeal swallows, which could also result in delayed elevation of larynx and aspiration. Individuals with stroke to right hemisphere are more likely to develop aspiration when compared to their left hemisphere counterparts. Hence the left cortical stroke is easier and faster to return to the normal oral intake when compared to right hemisphere cortical stroke.

When the lesion is in both the hemispheres, there are higher risks of aspiration. It has been reported that both the hemispheres are involved in swallowing, but the dominance of lateralisation can vary from individual to individual. Indirect evidence suggests that when it is the dominant hemisphere that is being damaged by stroke, dysphagia is more likely to happen. Often, patients post stroke are generally not aware of their swallowing difficulties and may not be able to adjust to their oral intake so as to compensate the deficits.

Effect of subcortical stroke on swallow

Structures beneath the cerebral cortex and above the medulla oblongata are the structures considered to be the subcortical structures performing complex motor and non motor function. Subcortical structures include the diencephalon, basal ganglia, brainstem, cerebellum and spinal cord. These structures are responsible for sensory and motor processing of different functions including the swallowing as they receive extensive inputs from cortex, peripheral sense organs and stretch receptors.

Subcortical lesions affect the motor and the sensory function to and from the cerebral cortex. Lesion in the subcortical structures causes slight delays in oral transit time, mild delay in triggering of pharyngeal swallow and mild to moderate impairments in timing of neuromuscular components of the pharyngeal phase of swallow (Logemann et al., 1993). Few stroke individuals have also shown aspiration before swallow. This was attributed to pharyngeal swallow delay which could be before or after the swallow as the neuromuscular control at the pharyngeal level is impaired.

Effect of high brainstem stroke (Pontine) on swallow

Lesion in the pontine area results in severe hypertonicity. For the structures involved in swallowing, the hypertonicity is evident in pharynx manifested as delay in pharyngeal swallow triggering or absent swallow, reduced elevation of larynx, crico-pharynx dysfunction, paralysis of pharyngeal wall. Recovery is found to be slow and difficult.

Effect of lower brainstem stroke (Medulla) on swallow

There are major nuclei like nucleus tractus solitarius and nucleus ambiguous present in the medullary region and have major function in swallowing (Jean & Car, 1979; Miller, 1982). Oral phase issues are seen in terms of exaggerated tongue base, movement of hyoid bone, and also of sub-mandibular region in an effort to propel bolus via oral cavity with help of tongue. In the pharyngeal phase of swallow, the swallow is either a very weak or absent. There is a significant delay seen in triggering of swallow; usually 10 to 15 seconds of delay is seen. When there is a delay, it results in reduced laryngeal elevation resulting in cricopharyngeal region opening to be reduced. There are some instances when food residues are seen in pyriform sinuses. Unilateral vocal ford paralysis adductor type is also seen in some individuals (Jacob, Kahrilas, Logemann, Shah, & Ha, 1989; Kahrilas, Logemann, Krugler, & Flanagan, 1991).

Effect of multiple strokes on swallow

Multiple strokes to individuals are more harmful and risky. They have more significant abnormalities when compared to those with a single episode of stroke. In the oral phase, the oral transit time is longer at around more than 5 seconds with repetitive movement of tongue and the overall function of oral cavity is slowed. In the pharyngeal phase, elevation of larynx and the laryngeal vestibule closure is reduced. The pharyngeal swallow is triggered late at over 5 seconds. Sometimes the food might be pocketed in the pharyngeal wall or in the pyriform sinuses.

The various lesion sites of brain can affect all or any of the phases of swallow including the pharyngeal phase of swallowing. In pharyngeal phase, hyolaryngeal elevation is an important event as it is a core mechanism for protection from aspiration. Mistiming of the various movements of the structures and also the reduced hyolaryngeal elevation are risk factors that are known to be associated with aspiration in post-stroke survivors. Hence, the present study looks into the mechanism of this complex in post stroke survivors.

Hyolaryngeal excursion

One of the important events that occur in the pharyngeal phase is the hyolaryngeal excursion. The hyolaryngeal complex comprises of the hyoid bone, thyrohyoid membrane, and laryngeal cartilages and other associated skeletal structures and musculature. The hyoid bone is a freestanding bone that relies on the movement of surrounding muscles and structures for its position and support (Zu, Yang, & Perlman, 2011). The hyoid bone's movement is considered to play a critical function in swallowing (Ueda Nohara, Kotani, Tanaka, Okuno, & Sakai, 2013). Airway safety during swallowing can be compromised if the hyoid bone does not move anteriorly and superiorly enough. The movements of the hyoid are influenced by muscles attached to structures above the hyoid and the hyoid itself- hyolaryngeal elevator muscles, which includes the geniohyoid, mylohyoid, and anterior digastrics.

The hyolarynx connects the pharynx to trachea and the esophagus. This complex serves as the site of attachment for the cricopharyngeal complex forming the upper esophageal sphincter. In the pharyngeal phase of swallow the elevation of this complex is an important critical event as it is necessary to stretch open the UES where the larynx relocates itself away anteriorly from the path of the incoming bolus (Matsuo & Palmer, 2008; Okuda, Abe, Kim, &....Ide, 2008). This is accompanied by the movement of hyoid bone which moves anteriorly and superiorly during the reflex and returns to rest after the swallow. This is followed by the closure of the vestibule and opening of the UES. This is the way in which the airway is protected and bolus is directed to esophagus.

Assessment of hyolaryngeal excursion

An estimate of hyolaryngeal excursion can be obtained using Logemann's four finger test (1983). The index finger is placed behind the mandible anteriorly, which tells about the initiation of tongue movement, middle finger at the hyoid bone to check its movement, third finger is at the top and fourth at bottom of the of thyroid cartilage to define the laryngeal movement when the pharyngeal swallow is triggered. In this way, sub-mandibular movement, hyoid movement and laryngeal movement can be assessed during the swallow. Comparing the time elapsed between the initiation of tongue movement and hyoid and laryngeal movement, a rough estimate of oral transit time and pharyngeal delay time or the time taken from the initiation of swallow by the tongue until the pharyngeal swallow triggers can be made.

For more objective quantification of the hyolaryngeal excursion, instrumental evaluation is carried out. Instrumental assessments provide visual images of the oral, pharyngeal, and upper esophageal phases of swallowing and includes fluoroscopy, endoscopy, ultrasound, and manometry and many other instruments.

Videofluroscopic swallowing study (VFSS), also known as the modified barium swallow study (MBSS), is a commonly used procedure for direct visualization of oral, pharyngeal and upper esophageal function (Logemann, 1986). Various consistencies of food and liquid mixed with barium are introduced and visualized in real time. Asymmetry, stasis, cricopharyngeal dysfunction, aspiration before, during and after swallow can be detected. Various physiologies of different structures can be observed like lip closure, tongue control, bolus preparation and transport, any oral residue, initiation of pharyngeal swallow, elevation of soft palate, laryngeal elevation, anterior hyoid movement, pharyngeal contraction, UES opening, pharyngeal residue and esophageal clearance.

Fiberoptic endoscopic assessment of swallowing function (FEES) is a portable procedure that may be completed in outpatient clinic space or at bedside by passing an endoscope transnasally (Langmore, Kenneth, & Olsen, 1988) focusing on pharynx, from nasopharynx to oropharynx. Information on spillage before swallow, residue after swallow in valleculae, pyriform sinuses and pharyngeal wall, laryngeal penetration, aspiration and reflux can be obtained. Sensation of the hypopharynx and larynx can also be tested using FEESST (flexible endoscopic evaluation of swallowing with sensory testing) procedure. It is a two-channel scope to assess the sensory perception of larynx and to monitor the laryngeal adductor reflex, which is characterized by a brief closure of the true vocal folds. It provides information regarding the incomplete closure of larynx resulting in aspiration during aspiration. The lateral view also gives the movement of hyoid bone and the lifting of larynx.

Ultrasound uses high-frequency sound waves (2- 10 MHz) and receives the echoes which are then converted to real time images. It is typically used to assess the oral preparatory and oropharyngeal stages of swallowing. The kinematics of dorsal surface of tongue, oral transit time and the motion of hyoid bone can be studied.

Electromyography (EMG) is a non imaging technique which evaluates and records the electrical activity of the skeletal muscles. Commonly used procedure is Surface EMG (sEMG) where electrodes are placed under the chin and on muscles involved in hyolaryngeal elevation (digastric, stylohyoid, mylohyoid, geniohyoid, hyoglossus and genioglossus) and also on the thyroid cartilage. These muscles are activated once the swallow begins and hence used as a marker in the measurement of onset of swallow. sEMG has been used to measure the duration and amplitude of muscle contraction specific to muscles which move the hyoid during swallowing (Crary, Carnaby, & Groher, 2006). This can also be used as a biofeedback tool during therapy via the laryngeal elevators to explain the activation of hyolaryngeal muscles for a longer duration in the Mendelsohn maneuver.

Electroglottograph is used to measure the contact of vibrating vocal folds during voice production. This can also be modified to track laryngeal elevation. It provides bio feedback on extent and duration of laryngeal elevation during the swallows in which the patient is attempting to improve the swallow parameters. Perlman and Grayhack (1991) modified the frequency output response of the EGG and found that the EGG output can be used to identify maximum laryngeal displacement and the duration of laryngeal movement during swallowing.

The swallowing is associated with sounds which can be heard using listening device. Listeners hear the sound and interpret of what could be happening in the swallow or is there any impairment. For the same purpose cervical auscultation is used. It is non invasive, inexpensive, portable and can augment clinical assessment. It provides continuous monitoring of swallowing behaviours. Bolzan, Christmann, Berwig, Investemnts, and Rocha (2013) reported that in normal swallowing, there are three marked sounds in the pharyngeal phase, with two audible clicks corresponding to laryngeal elevation and the bolus transit through the UES and a third sound corresponding to expiratory murmur.

Factors affecting swallow and specifically the hyolaryngeal excursion

Swallow can be influenced by numerous intrinsic and extrinsic factors. Biomechanics of the normal swallow is found to be altered by the volume, texture, taste, method of delivery, age, taste, consistency and many other factors. These factors can be directly or indirectly influencing the swallowing mechanics. These modifications in the diet are frequently used for the specific management of individuals with dysphagia. These modifications suggested are usually based on studies done on normal aspects of swallowing. However, the results of these studies are not uniform due to subject variability, type of swallowing instrument used for assessment, bolus type, and number of swallows tested. Some of these factors and studies related to their effect have been elaborated below.

Intrinsic factors

Intrinsic or the internal factors are those which cannot be controlled like the influence of age and gender on the swallowing function.

Gender effects

The neurological control of swallowing being influenced by gender has no much evidence. However, it is found that females have longer duration for clearance from pharynx and longer oro-pharyngeal transit when compared to males. The changes seen in the males and females are attributed to the differences in the physiologic system between the gender (Dantas, de Aguiar Cassiani, Dos Santos, Gonzaga, Alves, & Mazin, 2009). The gender differences could be related to the differences in diameter of pharynx as the females have smaller head and neck structures than males. The duration of hyoid movement is shorter in males and bolus volume swallowed by females is also less as they have small pharyngeal and upper oesophageal sphincter area. The oro-pharyngeal transit is slower than observed in males as females have to accommodate and safely pass the bolus into oesophagus. Ishida, Palmer, and Hiiemae (2002) stated that resting hyoid position is lower for males compared to females, and maximum upward position is almost same for both. This explains the reason for upward displacement to be greater in males compared to females.

Alves, Cassiani, Santos, and Dantas (2007) conducted a study among 111 healthy adults (75 women) within the age range of 24-77 years, to evaluate the gender effect on timed water swallowing test. Results revealed shorter inter swallow interval in women, where as in men, faster swallowing velocity and higher volume capacity. The authors primarily attributed the results to the anatomical variations between men and women (larger oral and pharyngeal cavity in men). Authors also postulated the possible involvement of differences in the coordination of swallowing and breathing, and other physiological aspects.

Im, Kim, Oommen, Kim, and Hawn Ko (2011) investigated the effect of different consistencies like water, thick liquid, and puree on 40 subjects of different age and gender groups by using videofluorscopic swallowing examination (VFSE). Each participant was provided with two trials of each consistency at 5mL each. The pharyngeal transit duration (PTD) was examined. Results revealed that PTD was shorter in males than in females. This was attributed to the greater activity of muscles in pushing the bolus back towards the esophagus.

Contrary to their study, Kelly in 2016 suggested that gender had no influence on swallowing. It does not have an effect on how fast an individual swallows a bolus or how strongly the hyolaryngeal muscles contract when swallowing. But they found a difference in duration and amplitude due to wide variation in terms of the anatomy and physiology of the hyolaryngeal muscles that exists in males and females, where females swallowed for longer durations and with greater amplitudes than males. Though the mean values were larger in females but there was no significant difference in duration and amplitude across the genders.

Age effects

There are lot of anatomical variations in the swallow mechanism between children and adults. The infant is not an anatomical miniature of the adult. The oral cavity of the child is filled by tongue resting between teeth and sits against palate with sucking pads in the cheeks in the buccinators. This makes sure that stability to the jaw is provided, for more efficient sucking and to develop coordination of jaw, lips, tongue and cheeks with a very small size of mandible. When an infant is growing, he is developing the sucking coordination. During this time the sucking pads may be reduced or absent. Thus, the early coordination lacks the anatomical support available to the newborn with this degree of oral control.

Children do not have a definite oropharynx and obtuse angling of nasopharynx at skull base. When the soft palate and epiglottis grow away from each other and are no longer in contact, the baby looses a valve which helps keep food in the mouth until the pharyngeal swallow is initiated. The older infant or child with poor oral control of the bolus may then have food fall over the back of the tongue into the valleculae or airway before the swallow is triggered. On the contrary, the adults have a large sized mouth where the tongue is found to be resting on the floor of mouth, elongated pharynx and hence a clear distinction between oropharynx and pharynx is seen and is right angle at skull base of nasopharynx. The buccinators is used for chewing only and the mandible- maxillary relation is normal.

At the laryngeal level, children seem to have the airway which is less protected, as it has lower position in the neck, further the vertical epiglottis is narrow and half true vocal cords are made of cartilages. Adults have a flat and wide epiglottis and only almost one fourth true cords are made of cartilages. Infants are found to be greater risk for ear infections from food or liquid that refluxes upward into the nasopharynx due to horizontal positioning of Eustachian tube.

Swallowing mechanism is found to be changed in elderly population of age 65 years and above due to reduction in muscle mass and connective tissue elasticity. This can cause loss of strength in the muscles and reduced speed (velocity) of movement (Crary & Groher, 2003). The changes may also appear as early as 45 years. The speed of swallowing alone can distinguish between an old and young person (Crary & Groher, 2003). A majority of elderly individuals have some or the other kind of abnormality in the structures and a number of physiological changes that occur in the oral, pharyngeal or the esophageal stage (Ekberg & Feinberg, 1991).

There are several studies conducted in the elderly population which has suggested that the duration of oral stage swallow is longer when compared to the younger counterparts. This delay is attributed to higher threshold required to trigger the swallow and hence the triggering of the pharyngeal swallow is prolonged (Logemann, 1998; Gleeson, 1999; Crary & Groher, 2003; Aydogdu et al., 2007). The muscular movements are also prolonged which occur during the swallowing reflex (Aydogdu et al., 2007).

Not just at the oral stage, but the muscles of hyolaryngeal excursion can also be affected by age. In a study by Sonies, Parent, Morrish, and Baum (1988) reported that 80% of 19 subjects in an older age group required double or triple hyoid gestures to complete the swallow in comparison to 0% in the middle-age group. Not only the number of swallows was increased, but also the time required for the hyoid activity during the dry and wet swallows increased significantly with age (Sonies et al., 1988; Gleeson, 1999). Logemann, Pauloski, Rademaker, Colangelo, Kahrilas and Smith (2000) performed a study which found that after cricopharyngeal opening was attained, hyoid and laryngeal elevation continued in the young men but remained static in the elderly men. The authors suggested that these findings were due to elderly men having less muscular "reserve" compared to younger men (Crary et al., 2003).

A study was conducted by Robbins, Hamilton, Lof, and Kempster (1992) on 80 normal volunteers. All the volunteers were divided based on their age into four age groups. The group I, II, III and IV was referenced in terms of 25-45years, 45-65years, 65-70 years and > 70years age. Each group had 10 men and 10 women. Liquid and semisolid swallows were performed and simultaneously videofluoroscopy (VFSS) and manometry were recorded. Several parameters, including stage transition duration, pharyngeal transit duration, duration to UES opening and total duration of oropharyngeal swallowing increased with increase in age. The two youngest age groups had significantly shorter duration variables than the oldest group. A delay in initiation of maximal hyolaryngeal excursion primarily accounted for the longer duration with increased age. Significant durational changes also were found as a function of bolus consistency and presence or absence of the manometry tube. Females had a longer duration of upper esophageal sphincter (UES) opening. The stage transition duration, duration of velar excursion, and pharyngeal transit duration were significantly longer for higher consistency like the semisolid boluses when compared to liquid boluses. On the other hand, the UES opening duration was longer for liquid boluses when compared to semisolid bolus. The amplitude of pharyngeal pressures, duration of peak pharyngeal pressures, and rate of propagation of the contractions were not significantly different for age, gender, or consistency of bolus. The duration of the swallow gradually slows after age 45, and by 70 years of age, the swallowing process is significantly slower in time than in individuals under 45 years of age. No significant differences were found between age groups or between genders in UES pressure.

Kendall and Leonard (2001) studied patients 65 years and older diagnosed with dysphagia of unknown aetiology, excluding those with neuromuscular diseases or stroke and compared them with younger group individuals as controls to evaluate the effect of hyoid movement on UES opening. They found that in the older population with dysphagia, the coordination of swallowing gestures and bolus timing was intact but the hyoid elevation was slow, and the duration of maximal hyoid elevation was reduced.

Kim and McCullough (2008) did a retrospective review of videofluoroscopic swallowing (VFSS) exams in 40 normal subjects varying by age and gender and the vertical and anterior displacement of hyoid bone during oropharyngeal swallowing using 5mL and 10mL thin liquids. Age and gender differences were subjected to a repeated-measures one-way analysis of variance. In younger and older subjects a significant difference for anterior displacement of the hyoid bone during the swallow but not for vertical displacement was seen. No significant differences between male and female subjects were observed. Anterior displacement of the hyoid bone decreased with increasing age. This reduction may be related to muscle weakness. However, older people may adapt to preserve airway protection.

Similar results were found by Ragland, Park, McCullough, and Kim (2016) who examined the speed of hyolaryngeal excursion in different age and gender groups during normal swallowing using VFSS exams on 27 subjects of ages of 21 and 51 years and 17 subjects between the ages of 70 and 87 years. The speed of hyoid excursion in older population was significantly slower than in younger population which was attributed to an overall slowing of nervous system activities and weaker muscle strength. There was no gender or bolus volume difference or interaction in the speed of hyoid excursion.

Extrinsic factors

Extrinsic or the external factors are those characteristics of food which make systematic changes in the oro-pharyngeal swallow which include pattern of bolus introduction, bolus volume, viscosity, etc.

Pattern of bolus introduction

Cup drinking

The cup drinking pattern is a sequential event and hence is different from straw drinking. The larynx has to be elevated prior and early so that the airway is closed when the cup approaches the oral cavity for all the continuous swallows. Around 5 to 10 seconds, the airway is closed depending on the consecutive swallows produced by an individual (Martin, logemann, Shaker & Dodds, 1994). Lips have to maintain a proper lip seal so as to avoid anterior spillage of liquid bolus. The tongue has to propel the bolus repeatedly as there are simultaneous swallows happening until the tail of the bolus makes a contact with tongue base and pharyngeal walls. The UES has to repeatedly keep opening and closing with the each incoming bolus.

Straw drinking

Straw drinking is just a means to modify the liquid bolus placed in the oral cavity. The bolus has to be sucked to get the bolus to the oral cavity by creating suction by the pressure differences. The soft palate has to be lowered to the back of tongue and the muscles of cheek and face have to be contracted. Immediately suction is created within the oral cavity so that the bolus can be brought into the mouth. The suction will be stopped immediately once bolus reaches mouth and oral phase of swallowing begins. The soft palate will be elevated as the oral stage is initiated by tongue. Thus, drinking by straw is a simple way of how the food can be modified which is placed in the mouth and how airway keeps opening and closing. This method can be easily observed and assessed during the bedside evaluation. Airway must remain closed and the laryngeal complex has to be closed and elevated during the sequential swallow attempts and may differ based on single or multiple sips. Daniels and Foundas in 2001 identified that there were three definite airway protection patterns in a study on 15 healthy individuals during continuous straw drinking. They found that there was variation manifested in terms of protection by upper airway. The laryngeal vestibule remained closed even when there was variation in length of time. Hypopharyngeal accumulation on repeated straw swallows before bolus moves into esophagus was found in younger and older normal subjects. It was also found that throughout the straw drinking the larynx had to be elevated.

Volume effects

Bolus volume directly affects the change in the swallow patterns, especially the oropharyngeal phase of swallows. Most studies that have examined the effects of volume have used 1mL to 20mL. When a small change in bolus volume is induced, it automatically causes change in the oral phase which is followed by the pharyngeal trigger for pharyngeal phase to be initiated and finally the oesophageal phase of swallow has to begin and completed separately. While large volume of bolus causes oral and pharyngeal phase to happen simultaneously, as the timing of the tongue base retraction to contract anteriorly and medially and move towards pharyngeal walls coincides. Hence, the pressure created due to any amount of bolus is due to the tongue base movement and pharyngeal walls towards the bolus trail.

Increasing the volume of bolus will automatically increase the bolus transit time as it is observed by sustained laryngeal elevation and hyoid excursion. In addition, when the volume of the bolus is larger, the duration of laryngeal closure and UES opening is increased, but a decreased duration of tongue base contact to posterior pharyngeal wall is also observed (Kahrilas, Lin, Logemann, Ergun, & Facchini, 1993; Lazarus et al., 1993; Bisch Logemann, Rademaker, Kahrilas, & Lazarus, 1994).

Viscosity effects

As the bolus viscosity is increased, the pressure generated by the base of tongue and the walls of pharynx are automatically increased and the activity of various muscles involved with these structures also increase (Dantas & Dodds, 1990; Dantas, Kern, Massey, Dodds, Kahrilas, & Brasseur, 1990; Reimers-Neils Logemann, & Larson, 1994). Automatically the various valve functions are also found to be increased in duration like the velopharyngeal closure and upper esophageal sphincter opening and laryngeal closure, as the viscosity of the liquid introduced is increased.

Physiologically, many studies have proved that when the bolus viscosity is increased, it results in an increase in lingual-palatal contact pressure, pharyngeal pressure and upper esophageal sphincter relaxation and reduced speed of bolus transit (Pouderoux & Kahrilas, 1995; Chi-Fishman & Sonies, 2002; Butler, Stuart, Castell, Russell, Koch, & Kemp, 2009; Dantas, Dodds, Massey & Kern, 2009).

There are various studies reported in support of changing the bolus volumes and bolus viscosity and their effect seen on the hyolaryngeal mechanics. Dantas, Kern, Massey, Dodds, Kahrilas, Brasseur, and Lang, (1990) investigated 10 healthy volunteers and used nectar viscosity of 200 cP to paste viscosity of 60,000 cP across different volumes of intakes of 2mL, 5mL, 10mL and 15mL. They found that when the bolus velocity rose from thin liquid to paste viscosity, the bolus velocity was reduced, but the pharyngeal transit time was increased. Along with that it was found that anterior tongue movement at the base had an earlier onset, there was superior palatal movement, anterior laryngeal movement, and UES opening with the increase of bolus volume. However, they also found that there was no remarkable effect of volume of bolus between both the bolus types.

Leonard, Kendall, McKenzie, Gonçalves, and Walker (2000) in a study on 60 individuals of age range 18 to 73 years of age including 30 males and 30 females. They introduced three liquid boluses of different volumes of 1cc, 3cc and 20 cc and evaluated the hyoid bone movement and larynx-to-hyoid bone approximation. Lateral views were obtained of the same using VFSS. It was found that hyoid elevation was greater in males than across all the bolus volumes. They also reported that with increase in bolus volume the extent of elevation of hyoid also increased. The larynx to hyoid approximation was also found to be significantly larger in males itself when compared to females. But the approximation did not vary with increase in bolus volume. The interrelationship of the various anatomical structures reports an overall reduction in hyoid kinematics for oropharyngeal swallowing in females when compared to males. Gender differences were attributed to the hyolaryngeal anatomy and individual physical properties. Secondary or associated factors may include deglutitive pressures and suprahyoid–infrahyoid muscle contractile force. However, male–female differences based on structural and morphological characteristics do not change swallowing efficiency or the outcome of ingestive behaviors.

Chi-Fishman and Sonies in 2002 used Ultrasonography on 31 healthy volunteers and tracked hyoid displacements from digitized images of 612 swallows. The subject for the study included 16 males and 15 females in age range of 20 - 39 years, 40 – 59 years and 60 – 79 years with no swallowing difficulties or any medical conditions. Subjects were ingested with bolus of thin juice, nectar thick, honey thick and spoon thick consistencies. Boluses were given at 5mL, 10mL, 20mL and 30mL. 20 swallows were obtained with 2 trials of each bolus from each subject. Measures of movement durations, maximal amplitudes, total distances, and peak velocities were subjected to repeated measures multivariate analyses of variance with viscosity, volume, age, and gender as factors. Results showed that spoon-thick swallows had the greatest pre swallow gesture and total movement durations. Significantly greater maximal amplitudes, forward peak velocity, and total vertical distance were found for when swallow was for larger-volumes. Older subjects had longer start-to-max duration (though shorter pre swallow gesture and total movement durations), greater maximal vertical amplitude, longer total vertical distance, and greater backward peak velocity than younger subjects. Results support the essentiality to examine the relationships between the kinematics to accommodate with different tasks and the motor control strategies. It also supports how the suprahyoid–infrahyoid structures adapt functionally and is compensated in older adults.

Nagy, Molfenter, Péladeau-Pigeon, Stokely, and Steele (2015) aimed to study the hyoid velocity changes when the consistency of the bolus was increased and the volume kept constant. 20 healthy participants, 10 males and 10 females were included in the study. The food bolus used included 3 boluses: nectar thick, thin and ultra thin liquid barium at 5mL volume in a randomized order. Each swallow was recorded in lateral view using Kay PENTAX digital swallow workstation. The recordings were processed by splicing of the video fluoroscopy recordings frame by frame. By frame to frame tracking of movement of hyoid, the onset of hyoid movement, peak of hyoid velocity and also peak of hyoid movement was calculated to derive measures of velocity for X, Y and XY movement directions planes. The distance and durational parameters were further derived. Results were seen as increased velocities and peak velocities for nectar thick bolus when compared to other bolus thin and ultra thin liquids. Anterior hyoid movement distances were greater and could be attributed to shorter movement duration when nectar thick bolus was introduced. Peak to peak velocities of movement of hyoid were also found to be larger for nectar thick liquids and thin liquid but not for ultra thin liquid. They concluded that thickened liquid boluses may improve airway protection, as closing the laryngeal vestibule is timed properly.

However, there have been contradicting views also when the changes are made in the bolus volumes and bolus viscosities. Nascimento, Cassiani, Santos, and Dantas (2015) administered video fluoroscopy on 30 healthy volunteers subjected to 5mL and 10mL of thick liquid barium and honey thick barium to measure the duration of oral transit, pharyngeal transit, pharyngeal clearance, upper oesophageal sphincter opening, hyoid movement, oropharyngeal transit, and the relation to pharyngeal clearance duration/hyoid movement duration. They found that whenever a bolus of 10mL was introduced, it resulted in a longer UES opening duration, than when a 5mL of bolus was introduced for both the consistencies. The pharyngeal transit time was not affected by bolus volumes and was longer for honey thick bolus than for thick liquid. There was no significant difference observed with bolus volume or consistency in the relation between pharyngeal clearance duration and hyoid movement duration.

Hyolaryngeal excursion in post stroke survivors

Hyolaryngeal elevation is a important mechanism for protection from aspiration. There are various authors who have looked into the action of this complex in comparison to healthy individuals.

Kuhl, Eicke, Dieterich, and Urban (2003) studied the vertical laryngeal excursion during swallowing in 42 healthy individuals of mean age 57 years using Ultrasonography. They were compared to 18 individuals with neurogenic dysphagia including stroke using thin liquid of 10mL. They found that individuals post stroke had the most pronounced reduction of laryngeal elevation and also the mean distance of hyoid to upper end of hyoid, when compared to healthy individuals and other neurogenic dysphagia conditions like amyotrophic lateral sclerosis, chorea, and multiple sclerosis.

Paik et al., (2008) compared the motion of epiglottis and hyoid bone in normal healthy adults and patients with dysphagia due to different etiologies. VFSS was performed to measure the horizontal and vertical excursion of the hyoid bone, rotation of the epiglottis, the hyoid bone trajectory and epiglottis trajectory during swallowing. A significant reduction in hyoid bone excursion and rotation of the epiglottis was observed in patients with myopathy but not in stroke patients. Stroke patients produced displacement patterns with multiple peaks but normal maximal excursion. Hence they concluded that the movement of hyoid bone extent and pattern varied with the aetiology of swallowing dysfunction.

Kim and McCullough (2009) conducted a study on 60 individuals with stroke. 22 patients had aspiration while rest did not report of any aspiration. VFSE was administered for two swallows of boluses 5mL and 10mL of thin liquids. Laryngeal aspiration and vertical & anterior displacement of hyoid bone were studied. Hyoid movement using VFSE was recorded. The sequence of the displacement of hyoid was digitized using S- VHS tape which provides clear images for manipulation. Picture frame for each swallow was generated and further analysed. Results revealed no significant difference between the aspirators and non aspirators for the hyoid vertical and anterior displacement, however the maximum anterior displacement was little greater in non aspirators than the other group. In general, both the groups had greater maximum vertical displacement than the anterior displacement. Aspiration before and during the swallow is attributed more to the pharyngeal swallow trigger than to the maximal extent of hyoid excursion.

Zoratto, Chau, and Steele (2010) investigated the physiological source of dual-axis swallowing accelerometry signals in 43 participants using 125 teaspoon-sized thin liquid barium swallows, in individuals with suspected neurogenic dysphagia like stroke, neurodegenerative disease, or brain injury. The movement trajectories of the hyoid bone and arytenoid cartilages from lateral VFSS were recorded and compared with the trajectories to time linked signals obtained from a dual axis accelerometer placed on neck anterior to cricoid cartilage. The main findings were that both the hyoid bone and larynx contribute significantly to the dual-axis accelerometry signal over the time course of a swallow.

Hans, Shin, Jun, Park, Ko, Choi, and Kim (2016) examined 58 post stroke survivors of age 60 years or greater using VFSS and divided them into two groups based on the presence of aspiration and absence of aspiration. They found that during oral stage, for the stroke survivor group with aspiration, 73% showed delayed initiation of the swallow, but for the stroke survivor group without aspiration, just 47% showed delayed initiation of the swallow, indicating that stroke survivors with aspiration had slow swallowing response. This indicated less sensory and motor control of the posterior tongue than those in the other group. It was found that post stroke individuals with penetration or aspiration had highly significant occurrence of delayed initiation of the swallow and reduced hyolaryngeal elevation than those without penetration or aspiration. They also found that the hyolaryngeal elevation was reduced in 88% of stroke survivors with aspiration indicating less airway protection or reduced upper oesophageal sphincter opening during the pharyngeal swallow, however for stroke survivors without penetration or aspiration, only 37% showed a reduction in elevation of hyolaryngeal complex. They concluded that hyoid and laryngeal elevation is clinical indicator of aspiration and penetration and can be used in treatment for stroke survivors.

Zhang Zhou, Wei, Yang, Wang, Zhou, and Villegas, (2016) explored the ability of laryngeal elevation velocity to predict the nature of aspiration in patients with acute ischemic stroke. Eighty nine acute ischemic stroke patients with a mean age of 59.31±11.46 years who were treated during 10 month period were included in the study. VFSS was used as they were asked to swallow materials of different textures (diluted, pudding-like, cookies) along with barium. VFS study was done to check for the relationship between the abnormal indices in the oral and pharyngeal phase and used univariate analyses. They found that 23% of the stroke patients had aspiration when 5mL of diluted barium was swallowed. They also attributed aspiration to be related to age, the reduced laryngeal elevation velocity and duration, delayed pharyngeal phase, pharyngeal transit time, abnormal epiglottic tilt, and invalid laryngeal elevation before true swallowing, and duration of upper oesophageal sphincter (UES) opening. Logistic regression analysis unveiled a reduced laryngeal elevation velocity prior to vestibule closure and was predictive of aspiration independently. This was attributed to a decreased contraction velocity of the muscles involved in hyolaryngeal elevation.

Factors affecting swallow, specifically the hyolaryngeal excursion in post stroke survivors

There have been various studies that investigated the range of hyolaryngeal elevation in normal and post stroke individuals using different bolus volume and consistencies. Bisch, Logemann, Rademaker, Kahrilas, and Lazarus (1994) used 1mL liquid bolus and 1mL pudding bolus on 10 normal subjects, 10 patients with mild dysphagia after stroke and 8 severe neurologically impaired patients with moderate to severe dysphagia, to measure the outcome of bolus viscosity on pharyngeal measures. They found that in healthy persons pharyngeal delay time was shorter as the bolus viscosity increased. He also found that in severe neurologically impaired patients and in stroke individuals when the viscosity increased, the pharyngeal delay time and the transit time was shorter and pharyngeal response time was longer. They concluded that increasing viscosity of bolus in severe neurologically impaired persons can result in increase in the complete time span of swallow.

Oommen, Kim and McCullough (2010) investigated how temporal measures are affected by the changes in bolus consistencies and bolus volume in post stroke individuals who had aspiration and those who did not have aspiration. 52 stroke patients were recruited and 22 healthy individuals were subjected to VFSS at 5mL and 10mL in thin liquid bolus, nectar thick bolus mixed with barium sulphate powder. Stage transition duration (STD) and laryngeal closure duration (LCD) were calculated. LCD was time between the first and last contact of the inferior surface of epiglottis and arytenoids. STD is time between the passage of bolus head from the mandible to the onset of hyoid excursion when is the maximum. ANOVA was performed for analysis of data. It was found that the stroke individuals with aspiration had longer STD for all the bolus consistencies and volumes. There was difference which was significant among the normal healthy individuals and post stroke individuals. However the STD values between aspirators and non aspirators was not significant statistically. LCD was not significant for the stroke group with aspiration and with no aspiration and also for the group of healthy individuals. LCD was unaffected with the change in bolus volume and bolus consistency.

Choi, Ryu, Kim, Kang, and Yoo (2011) studied 70 participants who were diagnosed with oropharyngeal dysphagia of unspecified origin using videofluroscopy swallow study. Thin fluids and thick fluids were used and different physiological variables of the process of swallow were measured. Based on the findings in the VFSS, the participants were divided into thick group aspirators, thin fluid aspirators and those with no aspiration. Among the 70 patients, 23 were thick fluid aspirators, 20 of them had thin fluid aspiration and no aspiration in remaining 27. This suggested that aspiration can vary with the changes in food viscosity. They found that pharyngeal contraction and upper oesophageal sphincter opening were reduced for the thick fluid aspirators and the same was attributed to the reduced extent of hyolaryngeal elevation. In thin fluid aspirators, the latency of swallowing reflex was prolonged, the transit time at the pharyngeal level and the interval in the transfer of bolus between the vallecula and elevation of larynx were significant factors of risk for these individuals. Hence, they concluded that as the bolus viscosity increased, the hyoid elevation decreased.

Rofes, Arreola, Mukherjee, Swanson, and Clavé (2014) used nectar thick Xanthan Gum on patients with oropharyngedal dysphagia which included 66 with stroke and 13 with other neurodegenerative diseases and compared it with 14 healthy participants when thin liquids, nectar thick and spoon thick boluses were introduced. They found no change in velocity of bolus or timing of the oropharyngeal swallow response. Also at the spoon thick viscosity, the bolus velocity decreased. But, they also reported that the prevalence of aspiration according to the Penetration aspiration scale score reduced as viscosity of bolus was increased. Prevalence of aspiration was 12.7% with thin liquid, 7.7% with nectar-like and 3.4% with spoon-thick viscosities.

Park, Sim, Yang, Lee, ... & Kwon, (2016) examined on 10 stroke individuals to check if by changing the bolus volume i.e. by increasing the volume it can improve penetration and aspiration. VFSS using two swallow at three bolus volumes of 2mL, 5mL and 10mL of barium thinned liquid with water. Pharyngeal delay time (PDT) and Penetration aspiration scale (PAS) were determined after looking at the action of swallow in real time and blind manner also. Results revealed that for 5mL and 10mL of thinned barium, the PDTs were shortened when compared to 2mL. At 2mL it was found that PDT was around 1.02 sec, at 5mL, PDT was around 0.49 and it was 0.36sec for 10mL. With increase in PAS score and increased bolus volume there was no significant difference observed. They concluded that when the bolus volumes are increased, the pharyngeal delay time is reduced, but this did not seem to affect the penetration or aspiration.

Wu et al., (2018) investigated data from 40 patients post stroke with dysphagia and compared them to 40 normal healthy individuals. They had to swallow blouses of different viscosities. Stimulus included water, nectar like food and pudding like food. Surface electromyographic potentials (sEMG) were recorded immediately as the swallow was initiated till the swallow was terminated. The electrodes of sEMG were placed on submental muscles (SMs) and the infrahyoid muscles (IMs). Results were seen as no significant difference in terms of change in age, gender and body mass index between both the groups. Significant difference was seen in duration of swallow at SMs and IMs in all the three viscosities in each individual group. They found that as the bolus viscosity was increased, the swallow duration increased seen in the pharyngeal transit time. Also there were statistically significant differences seen between the two groups with change of bolus consistency. The activity of SMs and IMs were longer in participants with stroke; especially the activity of SMs was more when the pudding consistency was introduced. The increased duration of swallow in stroke individuals was attributed to increased time for tongue to push the bolus back. The study concluded that as the bolus consistency is changed, the swallowing activity of muscles also changed in terms of duration. Thus, activating the activity of the SMs will improve the swallowing ability of patients.

The systematic review of the literature shows that there is presence of swallowing difficulty in individuals with stroke. There have been contrasting views in the studies investigating the hyolaryngeal excursion in normal healthy individuals and post stroke individuals. A few studies have reported that there is no significant difference (Park et al., 2016) or increased duration of hyoid elevation in stroke survivors (Kahrilas, Lin, Rademaker, & Logemann, 1997; Rofes, Arreola, Mukherjee, Swanson, and Clavé, 2014; Wu et al., 2018). On the contrary, previous studies have also found that there was reduced hyolaryngeal elevation in post stroke individuals, which could be leading to higher risk of aspiration due to incomplete airway closure (Paik et al., 2009; Choi, Ryu, Kim, Kang, & Yoo, 2011; Hans et al., 2016; Jing Zhang et al., 2016). Some researchers (Kim & McCullough, 2009; Oommen, Kim and McCullough, 2010) have reported no significant difference in the elevation of larynx superiorly in the aspirator and non-aspirator group of stroke individuals.

These studies have used varying bolus volumes (from 2mL to 30mL) and the different bolus consistencies (thinned liquid like water to paste thick gruels). Various instruments like Video fluoroscopic swallowing study (VFSS), Fiberoptic endoscopic evaluation of swallowing (FEES), Ultrasonography (USG), Scintigraphy and various other procedures have been used to measure the transit times, velocities. These studies have tried to correlate the changes in the bolus volumes and bolus viscosities with the various measures of swallowing using different methods. The findings of these studies, in general, indicate that different extrinsic and intrinsic factors have a direct effect on the swallow. However, most of the studies have been done on a wide age range of participants including individuals in various age groups but a very few are done on the clinical population. The duration and amplitude of swallow using accelerometry principles have been rarely been investigated and there is dearth of literature of the same. Keeping this in view, the present study was undertaken. The aim of the study was to investigate the hyolaryngeal elevation in post stroke survivors and to measure the duration and amplitude of hyolaryngeal excursion during the swallow for two different bolus volumes and viscosities post stroke survivors and compare it with the healthy individuals.

CHAPTER III

METHOD

The aim of the present study was to investigate the amplitude and duration of hyolaryngeal elevation in post stroke survivors using different bolus volumes and bolus viscosities and compare the same with neurotypical individuals using DASI^{TM}, Elixir Research, USA.

Participants

Two groups of participants were included in the study. The group I comprised of 10 individuals diagnosed with stroke in the age range of 39-59 years which constituted the clinical group. The participants in the clinical group for the study included those with stroke whose neurological insult (lesion site and presence of infarcts) was confirmed using the CT or MRI scans. Six individuals had an infarct in the cortex, one had subcortical lesion (basal ganglia/internal capsule) and three had lesions covering both the cortical and subcortical areas. Post stroke duration varied from 1 month to 6 years in the study. The details of each of the participant are described in Table 3.1.

Post stroke individuals included in the current study were not evaluated at the bedside but after they were discharged from hospital. They reported of swallowing difficulties immediately post stroke when admitted to hospital but they had gradually recovered from dysphagia. The post stroke survivors during evaluation were conscious, awake, mobile, and did not face any swallowing difficulties as reported by caregivers and the participants. The individuals were also found to be recovering from their speech, language, communication skills, and also physical disabilities. Similarly, the swallowing difficulties in these individuals would also be recovering as they did not report much difficulty with solids, semi solids and liquids. Most of them were attending speech-language and physiotherapy.

Most of the post stroke survivors were following regular diet and had no major swallowing complaints like aspiration, penetration, silent aspiration, choking of food, cough after swallowing, drooling, anterior spillage of food, slow or effortful swallow, sticking of food in throat, reflux or heartburn as reported and observed. The caregivers also reported that they were able to feed themselves and did not require any external help from them. There was no history of weight loss in the recent past as reported by the caregivers and participants. They were able to maintain good oral hygiene and chew swallow properly.

Those individuals with hemorrhagic stroke, previous history of neurological diseases, head and neck injuries, cancers or gastroenterological problems which might affect the swallowing function, those on medications affecting swallowing dynamics like antidepressants neuroleptics, anticonvulsants, benzodiazepines, antispastics, antihistamines, individuals with impaired conscious level, history of aspiration, pneumonia, tracheostomy or adenoidectomy, individuals with unstable general clinical status were excluded from the study.

Post stroke survivors were administered with the Gugging Swallowing Screen (GUSS) developed by Trapl, Enderle, Nowotny, Teuschl, Matz, Dachenhausen, and Brainin (2007). The GUSS offers a brisk screening and safe dependable method to recognise stroke individuals with dysphagia and risk of aspiration with various consistencies. GUSS looks into 2 aspects of swallowing. Indirect swallowing test is a simple saliva swallowing test along with vigilance, voluntary cough, throat clearing are assessed. A total of score 5 can be obtained in this section. Direct swallowing is performed sequentially for semisolids, liquid and solids swallowing trials. A total score of 15 can be obtained for this section. A combined total score of 20 is obtained for both the sections. A combined score of 20 is considered as no dysphagia. The individuals in the study had a score ranging from 18 to 20. A score of 20 indicates no dysphagia with minimal risk of aspiration. A score of 18 and 19 indicates slight dysphagia with low risk of aspiration and are to be referred to speech language therapist for further evaluations. Based on GUSS score it was found that two individuals had oral dysphagia (drooling) while three of them had pharyngeal dysphagia (cough on swallow).

Table 3.1:

Demographic details of the clinical group

Sl.No.	**Age (Years)**	**Gender**	**Total Score on GUSS**	**Site of Lesion**	**Stroke duration**
1.	39	Male	19	Left ICA occlusion	7 months
2.	59	Male	18	Left ICA and MCA infarct. With hypodensity in left temporo-parietal and occipital lobe in region	8 months
3.	51	Male	20	Acute ischemic stroke with normal brain study	6 years
4.	50	Male	20	Left MCA infarct	1 month
5.	43	Male	20	Sub arachnoid hemorrhagic transformation and intra ventricular extension	2 years

6.	42	Male	19	Left MCA ischemic infarct. Acute infract to fronto temporo and parietal lobes and left basal ganglia	1 year
7.	55	Male	19	Left MCA Ischemic infarct	2 years 6 months
8.	43	Female	20	Left ICA Ischemic infarct	1 year 10 months
9.	55	Male	20	Left MCA ischemic infarct. Acute infarct to left Insular cortex, temporal, parietal and frontal lobes.	2 months
10.	47	Male	19	Left MCA infarct. Acute infarct to fronto temporo parietal lobes and ganglio capsular region.	3 years 10 months

The group II consisted of 30 neurotypical healthy individuals in age range of 39-59 years which constituted the control group. The participants in group II were further subdivided into two subgroups based on 10 year age interval. The subgroups included 15 males and 15 females in age range of 39-49 years and 49-59 years. Individuals with no history of neurological diseases or psychological illness, no history of cognitive, communication and sensory deficits, ruled out through an informal assessment, were selected as the control group for the study. This group was administered with Eating Assessment Tool (EAT-10) questionnaire developed by Belafsky, Mouadeb, Rees, Pryor, Postma, Allen, and Leonard (2008) to screen for any swallowing difficulties. It is a self-administered, symptom-specific tool. The questionnaire consists of 10 questions and is scored on a 5 point rating scale. A score of 3 or higher on this tool is indicative of dysphagia. Only those with no dysphagia were included in the control group.

Cognitive deficits were screened in both the groups using Mini Mental Status Examination (MMSE) developed by Folstein, Susan and McHugh, (1975) to rule out any cognitive impairment. All the individuals scored above 24 which indicated no cognitive impairment.

The clinical and control group were also matched for socio-economic status using the NIMH socioeconomic status scale by Venkatesan (2011). The scale has sections such as occupation and education of the parents, annual family income and property to assess the socioeconomic status of the participants. Each of the section is scored on a 5 point rating scale, based on the level of occupation and education of the parents, annual family income and property. The scores of all the sections were summed up and matched with the SES status, a score of 0-4 indicated SES I; a score of 5-8 indicated SES II; a score of 9-12 indicated SES III; a score of 13-16 indicated SES IV and a score of 17-20 indicated SES V. The participants selected for the study belonged to SES III and IV status.

All the ethical procedures were followed for participation selection and participation. Prior, to the testing a written consent was taken from each of the participant or their caregivers after explaining the procedure of the study.

Instrumentation

Digital accelerometry for swallowing imaging (DASI™, Elixir Research, USA) version L8.0 was used for the purpose of collecting the data. This instrument uses the accelerometric principles to track the movement of hyolaryngeal complex during swallowing. DASI™ is software which runs on MS-DOS. DASI has a flexible piezoelectric accelerometer sensor used to measure the movement of the hyolaryngeal structure of the participant. Figure 3.1 depicts the instrument used in the study.

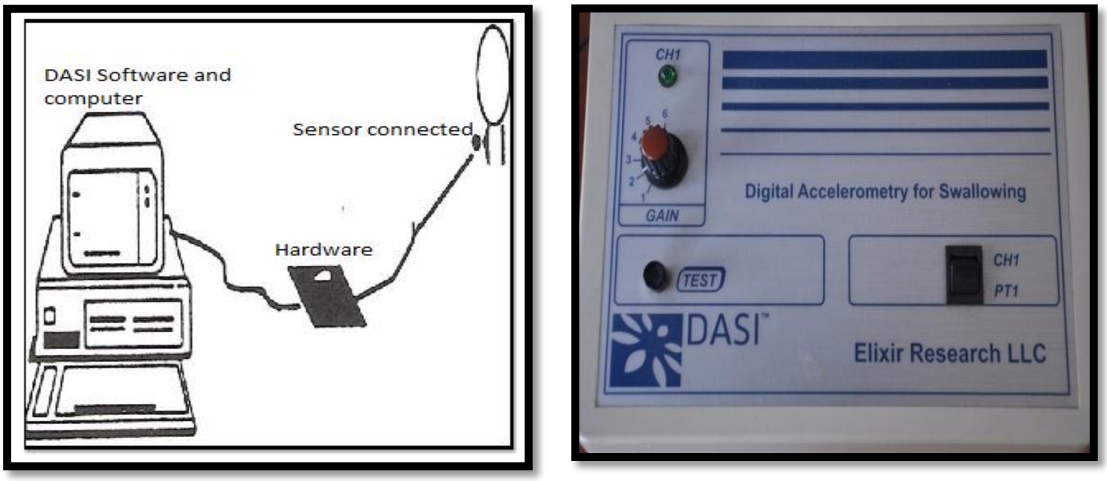

Figure 3.1: Instrument used for the study.

DASI™ is easy to use, flexible, provides a real time display and can be used for the purpose of assessment and intervention of persons with swallowing difficulty. This procedure is relatively easy, less time consuming and requires minimal response from the patient. Furthermore, this is a non-invasive and does not expose the individual to any kind of harmful radiation.

Materials used

- Measuring spoons: To measure the volume of liquids used for swallowing during the acquisition of the data from the participant. This has been shown in the figure 3.2.

Figure 3.2: Spoons used for measuring for 5 ml and 10 ml.

- Cotton and Disinfectant: To prepare the placement sites on the neck for the purpose of acquisition of data
- Thin liquid: Water
- Honey thick liquid: Yogurt
- Volumes: 5ml and 10ml

Both the groups of participants were administered with two different liquids of different viscosities and volumes. The viscosity of liquids that were used for the study included thin liquid purified water and honey thick liquid yogurt. Both the liquids were given at two volumes, 5ml and 10ml.

Procedure

A detailed demographic data was obtained from each participant in both the groups. The demographic details along with the informed consent with the parameters of interest of the clinical group and control group have been shown in Appendix I and Appendix II.

From the clinical group information regarding the location of lesion, onset of stroke, aetiology of stroke, and other relevant details was obtained. MMSE was administered on both the groups. EAT-10 on control group and GUSS on clinical group was administered.

Preparation of participants: The procedure of the recording was explained to each participant. The participants were made to sit comfortably on a chair in an upright position and the neck region was cleaned with cotton dipped in a disinfectant. In order to avoid the artifacts in the measurement, the participants were instructed not to make any unnecessary body movements and to keep still and not indulge in talking during the testing.

All the recordings were made in a single sitting for all the participants. The participants were instructed as follows "Be as relaxed as possible. Keep your head in normal position. Avoid any head or bodily movements and also avoid talking once the test begins. You will be given two liquids to drink. One is thin liquid which is purified water and the other is thicker liquid which is the yogurt. I will place this sensor on your neck and will also use a neck collar to tighten and also to ensure that the sensor is in place. The liquids will be given to you and you have to pour it in your mouth. Once I instruct you to swallow, you have to swallow and swallow the entire liquid at once. If you feel any kind of difficulty or if you are uncomfortable, indicate by raising your hand".

Initially a dry swallow was assessed using Logemann's four finger test (1983) to feel for the swallow and locate the thyroid and hyoid. In the four finger test, the index finger was placed under the chin anterior to mandible to feel for tongue movement. The middle finger was placed on the hyoid bone to check for the elevation of hyoid. The ring finger was at the top of the thyroid cartilage to feel the elevation of larynx. The little finger was placed at the base of the thyroid cartilage to feel the larynx return to rest. The elevation felt at the middle finger and the ring finger was marked as the site of recording for the study. The finger positions during the four finger test have been depicted in the figure 3.3.

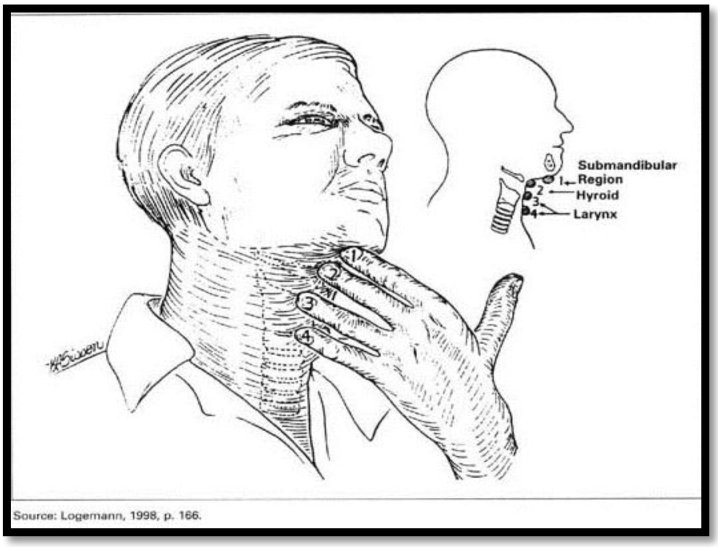

Figure 3.3: Finger positions during the four finger test.

The flexible piezo electric sensor was placed on the marked site identified in the four finger test i.e. the space between the hyoid and thyroid without interfering with the swallow. A neck collar was used to make sure that the sensor remains in place during the complete evaluation process. Hyolaryngeal movements were recorded as the bolus was introduced to the participant's mouth for the swallow to be completed. The piezoelectric sensor and the placement of the ssame has been depicted in figure 3.4.

Figure 3.4: Placement of piezoelectric sensor in hyolaryngeal area.

The following tasks were recorded for each participant. Figure 3.5 depicts the complete setup of the experiment.

Dry swallow: Each participant was instructed to swallow his/her own saliva as normally as possible without any effort. This task was done to establish a baseline and to familiarize the test procedure.

Thin Liquid: In this task, purified water was used. This liquid was introduced at two different volumes - 5mL and 10mL for both the group of participants.

Thick Liquid: In this task, yogurt which has a higher viscosity than water was used. This liquid was introduced – 5mL and 10mL for both the group of participants. The figure 3.6 depicts the flow chart of the procedure used in the study

Figure 3.5: Participant with the complete set up of the instrument.

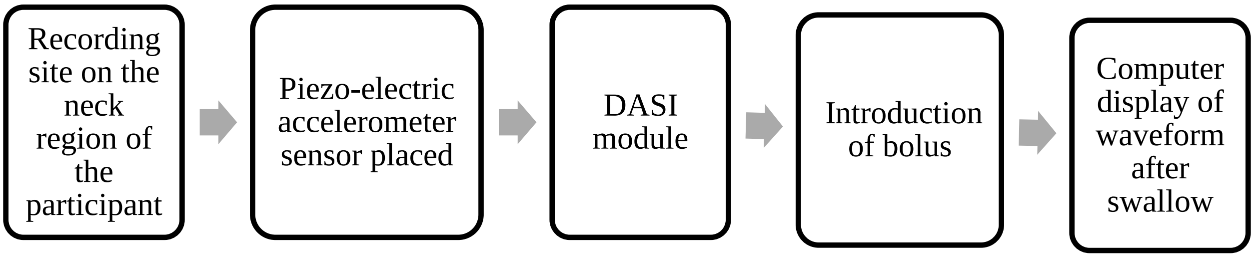

Figure 3.6: Flow chart of the procedure used in the study.

The movements of the hyolaryngeal complex during the swallow of thin and thick liquids at different bolus volumes were recorded and displayed. The amplitude and duration were obtained from these waveform as depicted in Figure 3.7.

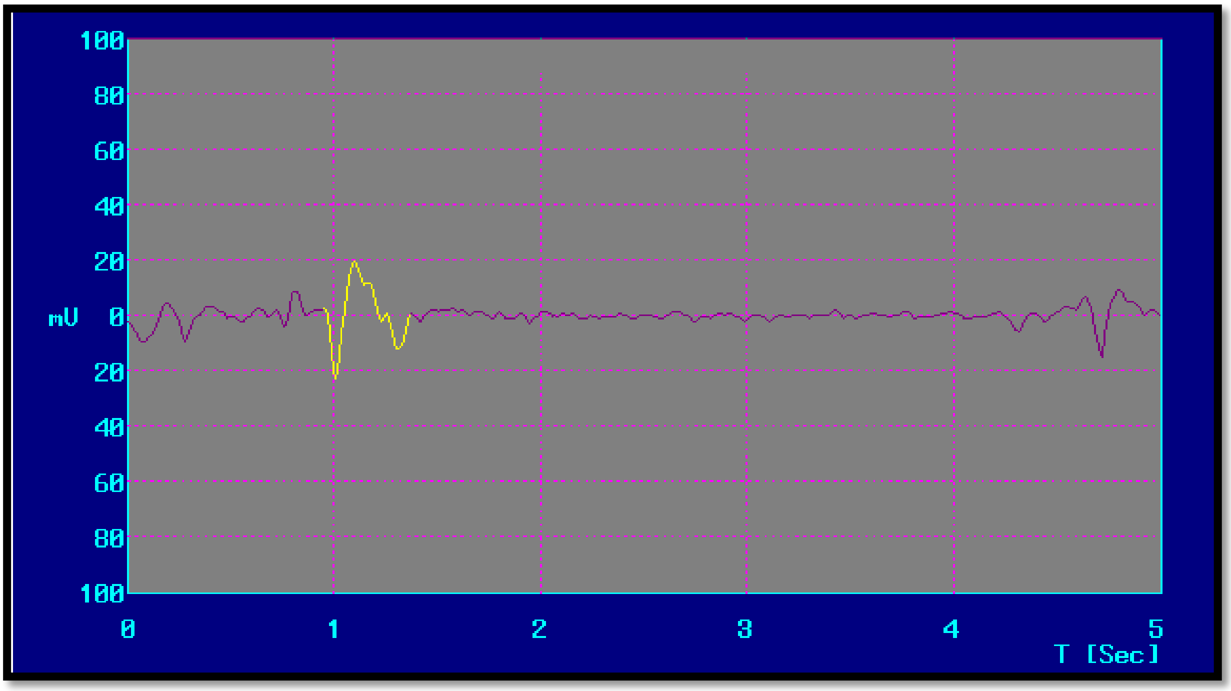

Figure 3.7: Sample waveform acquired for a participant.

Randomization of stimuli: The stimuli were presented randomly to the participants to counter balance the order effect. Three trials of each liquid volume and viscosity were obtained per participant.

Tests retest reliability

In order to ensure test-retest reliability, 10% of the samples were randomly selected and reanalyzed, after one week of the first recording from both the group of participants.

Analysis

From the recorded data, measures of interest were derived. The parameters of the swallowing were tabulated and analysed for each of the selected sample across the various bolus volumes and viscosities as listed below and depicted in figure 3.10:

- Duration in seconds from initiation to the termination of swallow in seconds represented on X-axis

- The peak amplitude of the swallow in micro volts on Y-axis

The independent variables were the two different viscosities of bolus (water and curd) at two different volumes of bolus (5 ml and 10 ml) and the two groups (control group and experimental group). The dependent variables were the amplitude and duration of hyolaryngeal excursion.

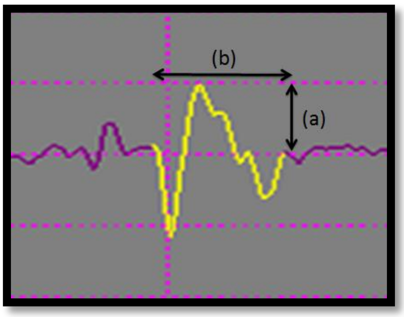

Figure 3.8: Parameters considered for the study (a) amplitude and (b) duration of swallow.

Statistical Analysis

The averaged data across all the swallow trials in terms of amplitude and duration for both the bolus volumes and viscosities for post stroke survivors and neurotypical individuals were fed to SPSS software version 20 and subjected to appropriate statistical analysis. Descriptive statistics were computed to obtain the mean, median and standard deviation for both the groups across all the conditions. Comparison was made across the two gender (males and females), across the two groups (neuro-typical and stroke survivors), across the two wet swallow condition (thin liquid and thick liquid) within each group and across the two different bolus volumes (5mL and 10mL) within each group. The results obtained are been presented and discussed in the next chapter.

CHAPTER IV

RESULTS AND DISCUSSION

The current study aimed at investigating the effect on hyolaryngeal excursion with different bolus volumes and bolus viscosities in post stroke survivors. The specific objectives of the study were to investigate the amplitude and durational measures of hyolaryngeal excursion during the swallow of two different bolus volumes (5mL and 10mL) and viscosities (water and curd) in post stroke survivors in comparison to neurotypical individuals.

Group I (clinical group) comprised of a total of 10 participants (9 males and 1 female) post stroke in the age range of 39 - 59 years. Age matched thirty neurotypical individuals (15 males and 15 females) constituted the group II (control group). All the participants were provided with two liquid bolus viscosities at two bolus volumes. Digital accelerometry for swallowing imaging (DASI^{TM}, Elixir Research, USA) version L8.0 was used to track the movement of hyolaryngeal complex during the swallow. The data was analyzed for mean amplitude in terms of micro-volts and mean duration in terms of seconds of the hyolaryngeal elevation for two different volumes and viscosities in both the groups. The values obtained from all the participants were totalled and averaged across all the participants. This was fed to the computer and subjected to statistical analysis using SPSS software. Appropriate statistical procedures carried out are listed below:

- Descriptive statistics was carried out to obtain mean, median and standard deviation.
- Cronbach's alpha test was used to ascertain the test- retest reliability.
- Shapiro-Wilk test was carried out measure normality of the data.

- Mann Whitney U test was computed to check for significant difference, if any, in the hyolaryngeal elevation across male and female participants of both the groups and between the clinical and the control group.
- Wilcoxon Signed Ranks test was done to check for significant differences, if any, between different bolus volumes and bolus viscosities within groups.

The results obtained from the statistical procedures described above have been presented and discussed under the following subsections

I. Normality of the data for control and clinical groups

II. Comparison across trials in terms of amplitude and duration

III. Test-retest reliability

IV. Between group comparison

   i. Comparison between male participants and female participants of control group

   ii. Comparison between control group and clinical group

V. Within group comparison across different bolus volumes and viscosities

   i. With respect to control group

   ii. With respect to clinical group

I. Normality of data

To check the nature of distribution of the data, normality test was done. The data from both the groups (clinical and control group) was subjected to Shapiro-Wilk test of normality. The amplitude and duration of the trials did not follow the normality trend. As normality was not present ($p < 0.05$) for the data, non parametric Friedman test was selected to analyze the data to compare across swallow trials in terms of amplitude and duration in both groups.

II. Comparison across trials in terms of amplitude and duration in both groups

Non parametric Friedman test was performed to verify for significant difference, if any, across swallow trials in each group. In view of the fact that there was no significant difference between the trials ($p < 0.05$), the average of all the three trials was taken and one value was obtained. Thus this averaged one trial represented each participant's amplitude and duration across different bolus volumes and viscosities. The averaged data of the swallow trials obtained was subjected to further statistical analysis.

III. Test-retest reliability

Test-retest reliability was computed for 10% (3 participants from control group and 1 participant from clinical group) of the total sample population using Cronbach's alpha test. The Cronbach's alpha values were greater than 0.90, indicating excellent test-retest reliability. The specific Cronbach's alpha values for the amplitude measures were 0.94 and for duration measures were 0.97. This indicated high test-retest reliability.

IV. Between group comparison

i) Comparison between male participants and female participants of control group

To check for any statistically significant differences in the extent of hyolaryngeal excursion across male and female participants with respect to different conditions of bolus volumes and bolus viscosities, descriptive statistics was carried out to compute the mean, median and standard deviation. The mean, standard deviation (S.D) and median for the different bolus volumes and bolus viscosities have been depicted in the Table 4.1. It was seen that the mean values of amplitude and duration of hyolaryngeal excursion values for male participants were higher in comparison to female participants.

Table 4.1:

Mean, Standard Deviation (SD) and median for different bolus volumes and viscosities for male and female participants

Measures			**Males**			**Females**		
			Mean	**S.D**	**Median**	**Mean**	**S.D**	**Median**
Water	Amplitude	5 ml	21.66	10.59	19.33	14.22	4.97	13
		10 ml	23.62	8.27	23	15.73	5.19	14.66
	Duration	5 ml	1.27	0.40	1.16	0.92	0.25	0.90
		10 ml	1.29	0.40	1.20	1.20	0.39	1.16
Curd	Amplitude	5 ml	21.48	6.94	19.33	16.40	6.63	13.66
		10ml	25.17	9.82	22	18.15	6.69	16.33
	Duration	5 ml	1.43	0.55	1.33	1.23	0.28	1.26
		10 ml	1.65	0.90	1.40	1.43	0.29	1.60

Mann-Whitney ‘U’ test was done to find significant difference, if any, across gender. The results of Mann-Whitney ‘U’ test revealed that there was a significant difference across gender among various wet swallow conditions. The results of the Mann- Whitney ‘U’ test have been depicted in table 4.2. There was a significant difference for 5ml water and a high significant difference for 10ml water and 5ml curd for the amplitude measure between males and females. There was also a high significant difference between males and females for the duration measure for 5ml water.

Table 4.2:

| *z* | *and p values for different bolus volumes and viscosities* across the two gender groups

Measures			/z/value	p value
Water	Amplitude	5 ml	1.99	0.04*
		10 ml	2.82	0.00**
	Duration	5 ml	2.57	0.01**
		10 ml	0.45	0.64
Curd	Amplitude	5 ml	2.42	0.01**
		10ml	2.20	0.96
	Duration	5 ml	0.64	0.51
		10 ml	0.042	0.96

Significant difference * $p < 0.05$ ** $p < 0.01$

The findings indicated only a significant difference between the amplitude of males and females for 5ml water, 10ml water and 5ml curd and a significant difference between the duration measure of males and females for 5ml water. However, the mean values for males were higher for the amplitude and duration measure under all bolus volumes and viscosities.

The higher mean values in males can be attributed to the anatomical and physiological differences seen in the two genders (Alves, Cassiani, Santos, & Dantas, 2007; Dantas et al., 2009). It was found that females have smaller head and neck structures, due which they have smaller pharyngeal and upper oesophageal sphincter area, which will influence the hyolaryngeal anatomy (Leonard, Kendall, McKenzie, Gonçalves, & Walker, 2000) and its movement. Additionally Wang, Chen, Lu, Guo, and Qiu (2013) found that the height of hyoid bone is more advanced in males than females. The length and width of the hyoid bone and the thickness of the greater horn of the hyoid bone were larger in males compared to females (D'Souza, Kiran, & Harish, 2013). Ishida, Palmer, and Hiiemae (2002) stated that resting hyoid position is lower for males compared to females, and maximum upward position is almost same for both. This explains the reason for upward displacement to be greater in males compared to females. An ultrasonographic study assessing hyoid kinematics (Chi-Fishman & Sonies, 2002) found gender differences in the related parameters and reported greater amplitudes in males compared to females. Having prominent larynx in males results in higher amplitude values. This is because the piezoelectric sensor picks up the movements better with a prominent larynx (the bending of the sensor is more when there is laryngeal prominence compared to when there is not). All these reasons could be attributed to the significantly higher mean amplitudes seen in the male participants when compared to female participants in the present study.

Certain studies have also reported significant gender differences, with higher duration of hyoid elevation in the male participants when compared to female participants. The larynx to hyoid approximation was also found to be significantly larger in males when compared to females (Leonard, Kendall, McKenzie, Gonçalves, & Walker, 2000). There is an overall reduction in hyoid kinematics for oropharyngeal swallowing in females when compared to males as seen in the present study. The results of this study are also supported by the findings of Dantas et al. (2009) who reported that pharyngeal transit time is slower and longer, as males take longer time to accommodate the bolus to safely pass it into oesophagus.

The observations made are however contradicted by Kelly (2015) who reported that female participants swallowed for longer durations and with greater amplitudes than males. Im, Kim, Oommen, Kim and Hawn Ko (2011) reported that pharyngeal transit duration was shorter in males than females. This was attributed to the greater activity of muscles of pharynx in males rather than females that are required in pushing the bolus back towards the esophagus during the swallow.

A study performed by Van den Engel-Hoek et al. (2012) on population younger than 70 years of age, found no significant difference on duration and amplitude between men and women. When evaluating gender and its effects on muscle activity and hyoid movement, Vaiman, Eviatar, and Segal (2004) reported no significant difference in muscle activity duration amongst men and women. The results were supported by other investigators who reported of no gender differences (Cichero & Murdoch, 2002; Youmans, & Stierwalt, 2005).

The differences in the findings obtained in the current study and other studies may be attributed to various factors like the anatomical differences in terms of overall size and dimensions of the participants. Most of the studies reported are on western population who have larger oral and pharyngeal volumes (Xue, & Hao, 2006) when compared to Indian population. A range of viscosities have being employed in different studies. Im et al. (2011) used different viscosities like water, thick liquid, and puree, while Kelly (2016) used cookie and pudding, whereas the current study used thin water and thick liquid curd. Bolus volumes considered in the different studies varied from 1ml to 20 ml, however, the current study employed only 5 and 10ml volumes. Further, instrumentation used also varied across studies with some using VFSS and FEES and others using Ultrasonography gives direct images of the movement of the hyoid and larynx. Accelerometer has been used in the present study which only tracks the movement of hyolarynx indirectly, which is rarely investigated.

ii) Comparison between control group and clinical group

To check if there was any significant difference in the extent of hyolaryngeal excursion across the control and the clinical group across different conditions (bolus volumes and bolus viscosities), descriptive statistics was done to compute the mean, median and standard deviation. The mean, standard deviation (S.D), median values for the different bolus volume and bolus viscosities were obtained and has been depicted in the Table 4.3. It was seen that the mean values of amplitude and duration of hyolaryngeal excursion values for clinical group were higher in comparison to control group.

Table 4.3:

Mean, Standard Deviation (S.D) and median for different bolus volumes and viscosities for control group and clinical group.

Measures			Control Group			Clinical Group		
			Mean	**S.D**	**Median**	**Mean**	**S.D**	**Median**
Water	Amplitude	5 ml	17.94	8.97	15.33	19.56	9.02	16.50
		10 ml	19.67	7.88	18.66	28.80	15.58	23.83
	Duration	5 ml	1.09	0.37	1.01	1.49	0.36	1.40
		10 ml	1.24	0.39	1.20	1.76	0.52	1.76
Curd	Amplitude	5 ml	18.94	7.16	18.50	20.83	8.53	17.16
		10ml	21.66	8.99	18.50	26.83	10.52	23.5
	Duration	5 ml	1.33	0.44	1.26	2.23	0.65	2.21
		10 ml	1.54	0.67	1.41	2.65	0.79	2.71

The data was further subjected to Mann-Whitney ‘U’ test to find the significant difference across the various conditions. The results of the test are depicted in Table 4.4. The results of Mann- Whitney ‘U’ test revealed that for thin liquid water (5mL and 10mL), a high significant difference was seen only in the amplitude of hyolaryngeal movement between the clinical and the control group. On the contrary, for honey thick liquid, highly significant differences was seen only in the duration of hyolaryngeal movement.

Table 4.4:

| z | and p values for different bolus volumes and viscosities across the control and clinical group

	Measures		/z/ value	p value
Water	Amplitude	5 ml	2.73	0.00*
		10 ml	2.78	0.00*
	Duration	5 ml	1.85	0.06
		10 ml	0.34	0.73
Curd	Amplitude	5 ml	0.70	0.48
		10ml	1.65	0.09
	Duration	5 ml	3.5	0.00*
		10 ml	3.59	0.00*

Significant difference ** $p < 0.01$

The findings from the present study indicate that the mean amplitude and duration values across all the bolus volumes and bolus viscosities were higher in participants of clinical group than participants of control group. The findings of the present study receives support from Kahrilas, Lin, Rademaker, and Logemann (1997) who used VFSS on 29 stroke individuals to measure the duration of laryngeal closure and attributed the delayed initiation and slow movement of deglutitive laryngeal elevation which was proportional to the severity of swallow dysfunction. This automatically resulted in longer duration of the laryngeal elevation as seen in the current study. Wu et al. (2018) also reported in a sEMG study that the activity of infrahyoid muscles was more in stroke survivors when compared to normal individuals and attributed this to increased time for tongue to push the bolus back in stroke individuals. When the tongue was placed upward, the bolus proceeded faster, and the swallowing process was open for longer periods of time, and therefore, the swallow duration was prolonged. The duration of the swallow automatically is increased as the infrahyoid muscles are more activated. Similarly Zoratto (2009) used accelerometry signals and found that the hyoid bone when elevated returns to rest at less slower rate in stroke persons i.e. the duration is longer to get back to the original position from its peak elevation.

However, most of the studies have reported that stroke individuals have reduced hyolaryngeal elevation. Perlman et al. (1992) reported that 25% of the patients had reduced hyoid elevation. Diminished elevation of the larynx may be designated to the slow contraction of the suprahyoid muscles linked with deviant muscle strength and diminished contraction velocity. Broniatowsk et al. (1999) reported that stroke patients with dysphagia may have impaired velar and hyolaryngeal elevation with diversified degrees of central laryngeal nerve paralysis. On the similar lines, Hans et al. (2016) also found that the hyolaryngeal elevation was reduced in 88% of stroke survivors with aspiration indicating less airway protection. Zoratto, Chau, and Steele (2010) also suggested that weak accelerometry signals (i.e., those with low acceleration values) indicate that the individual during swallowing is at higher risk of aspiration or penetration (Reddy et al., 1991) and is likely to be due to the effect of reduced hyolaryngeal elevation.

In the present study, there was a high significant difference with respect to amplitude for thin liquids. This could be attributed to the possible use of compensatory behaviour by the participants in the clinical group to overcome their swallowing difficulties, which they had faced immediate post stroke. In the Indian scenario, when individuals with stroke are admitted to hospitals, the medical team, in the absence of a speech-language pathologist/swallowing specialist, advises on methods like forced effortful swallow which increases the pressure exerted on all the areas in the oral and pharyngeal cavity. Sometimes they are also recommended some compensatory strategies to clear the residue from various areas of oral and pharyngeal cavity. These methods focus on prevention of secondary complications early after stroke and continue into the sub-acute stage to improve affected swallowing control and mechanics. It can so happen that even after discharge from hospital in the absence of any evident swallowing difficulties, individuals might continue to use the same compensatory/facilitatory techniques. This might have been the reason for increased amplitudes for especially for thin liquid (water), which is a daily necessity for life sustenance.

Additionally, there was a significant difference in the duration measure between neurotypical individuals and post stroke survivors for thick liquid. This indicates that individuals with stroke require larger duration and sustained hyolaryngeal excursion for longer time for thicker viscous liquid when compared to thin liquid bolus. It was seen that during the hyolaryngeal assessment, the time taken to swallow thick liquid was longer in post stroke survivors when compared to neurotypical individuals. Though, the individuals were instructed to swallow the complete bolus in one gulp, post stroke individuals made multiple attempts to swallow the thick liquid. The stroke individuals required double or triple hyoid gestures to complete the swallow in that was observed for thick liquid was more when compared to thin liquids.

The overall difference in values of amplitude and duration between the two groups can be attributed to the neurological insult in the clinical group. The change lesion site and size influences the hyolaryngeal elevation. The neural impulse or inappropriate conductivity to or from the central nervous system (CNS) may indirectly affect healthy peripheral striated muscular system. This may be the same for the muscles involved in hyolaryngeal elevation (Broniatowsk et al., 1999). The activity of hyolarynx depends on the motion of hyoid in junction with larynx and also the epiglottis. Stylohyoid, stylopharyngeus, palatopharyngeus, salpingopharyngeus, mylohyoid, anterior belly of the digastric, hyoglossus and geniohyoid are the muscles that are involved to elevate the hyolaryngeal complex (Broniatowsk et al., 1999).

However, DeLorenzo (2013) documented that timing and movement of the different structures that participate in the hyolaryngeal elevation in stroke individuals do not differ from those in normal participants. However, the speed and precision for all the structures is reoriented with the discrete movements of hyoid excursion and laryngeal elevation in comparison to the control participants. In the hyolaryngeal complex the movement of larynx is much advanced to the hyoid bone during the swallow which is the opposite of a normal swallow.

Post stroke individuals included in the current study were evaluated and included in the study after they were discharged from hospital and not at bedside.

They had swallowing difficulties immediately post stroke, but gradually had recovered from dysphagia. The post stroke survivors during evaluation were conscious, awake, mobile, and did not have any swallowing difficulties as reported by the participants and their caregivers. Most of the post stroke survivors were following regular diet and had no major swallowing complaints like aspiration, penetration, silent aspiration, choking of food, cough after swallowing, drooling, anterior spillage of food, slow or effortful swallow, sticking of food in throat, reflux or heartburn as reported and observed. The caregivers also reported that they were able to feed themselves and did not require any external help from them. There was no history of weight loss in the recent past as reported by the caregivers and participants. They were able to maintain good oral hygiene and chew and swallow appropriately.

The findings in post stroke survivors seen in this study when compared to other studies could also be attributed to the recovery and treatment availed for overcoming communication deficits. Most of the participants were attending speech-language therapy and were found to be recovering from their speech, language and physical difficulties. Similarly, the swallowing difficulties in these individuals had recovered as they did not report much difficulty with solids, semi solids and liquids during the time of inclusion in the study. Thus, it was seen that the improvement in physical and communication skills paralleled the improvement in swallowing. This could be possibly because of the muscle function overlap in speech and swallowing activities. Bahr and Hillis (2001) also speculated the same that speech and vegetative non speech functions share coordinate muscle components. Hence, the activities used in management of verbal skills would have directly or indirectly lead to the strengthening of the muscles involved in swallowing.

V. Within group comparison

Within group differences of amplitude and durational parameters of hyolaryngeal excursion by interaction among two conditions of different bolus viscosities (Thin liquid water vs. Honey thick curd) and different bolus volumes (5ml vs. 10ml) were compared. The findings as discussed earlier did not follow normality; hence Non parametric Wilcoxon Signed Ranks test was carried out to check for the significance of the above mentioned conditions as listed below:

a) With respect to control group

The values obtained in the control group were subjected to Wilcoxon Signed Ranks test for all the bolus volumes and bolus viscosities. The details of the findings of Wilcoxon Signed Ranks test are tabulated in the Table 4.5.

The mean amplitude and mean duration increased slightly when the volume increased at constant viscosities for both males and females (table 4.1). Wilcoxon Signed Ranks test revealed that there was a high significant difference (p=0.01) across volumes in both viscosities in both amplitude and duration measures.

Table 4.5:

| z | and p values for different bolus volumes and viscosities for control group

Measures			/z/ value	p value
Water	Amplitude	5 ml vs. 10mL	1.93	0.05*
	Duration	5 ml vs. 10mL	3.05	0.00**
Curd	Amplitude	5 ml vs. 10mL	2.76	0.00**
	Duration	5 ml vs. 10mL	3.18	0.00**
5mL	Amplitude	Water vs. Curd	0.77	0.44
	Duration	Water vs. Curd	2.86	0.00**
10mL	Amplitude	Water vs. Curd	0.76	0.44
	Duration	Water vs. Curd	3.11	0.00**

Significant difference * $p < 0.05$ ** $p < 0.01$

Increasing the volume of bolus will increase the bolus transit time as it is observed by sustained laryngeal elevation and hyoid excursion in the study. The larger volume swallow seemingly takes longer and results in much more vigorous bolus expulsion than a small volume. In addition, when the volume of the bolus is larger, the duration of laryngeal closure and upper esophageal sphincter opening is increased (Kahrilas et al., 1993; Lazarus et al, 1993; Bisch et al., 1994). Lazarus et al., in 1993 also reported the same that subjects have a significant increase in the duration of laryngeal closure and UES opening as an effect of increase in bolus volume as observed in this study. He attributed that the laryngeal closure is the protective mechanism where the laryngeal aditus is closed and when the volumes increases, the duration of this closure also increases.

Dodds et al. (1973) and Cook et al. (1989) likewise concluded that maximal hyoid excursion will be due to the increased bolus volume demands. In their study also they concluded that with a step wise progress in the bolus volume there is step wise progression of hyoid movement. This change could be attributed to the physiology of swallowing. The hyoid bone is suspended to larynx and attached to larynx with the help of suprahyoid muscles and attaches to skull and mandible. The hyoid elevation is possible with help of suprahyoid muscles. The amount of the bolus defines the magnitude of hyoid movement which is attributed to the afferent feedback from the brain which alters the quantitative features of swallowing. The hyoid movement anteriorly, affects the movement of other accompanying muscles like the UES, cricoid cartilage and the larynx. The hyoid bone pulls the larynx and hence there is a close relationship between both these structures. Thus, the feedback for sensory regulation during and after swallowing affects the physiology of swallowing. Thus, the volume of bolus can affect the duration and magnitude of the hyoid movement (Dodds, 1989).

The current study was also supported by Leonard, Kendall, McKenzie, Gonçalves, and Walker (2000) using VFSS on varying the bolus volumes from 1cc to 20cc, found that an increase in bolus volume resulted in the increase in the extent of elevation of hyoid. In swallows of larger volume, a longer time is assigned to the process which is exemplified by sustained laryngeal elevation and hyoid excursion as seen in the present study.

On the other hand, Ragland, Park, McCullough, and Kim (2016) reported no gender or bolus volume difference or interaction in the speed of hyoid excursion. Leonard, Kendall, McKenzie, Gonçalves, and Walker (2000) found larynx to hyoid approximation was also found to be significantly larger in males when compared to females, but the approximation did not vary with increase in bolus volume. Further, Maddock and Gilbert (1993) in a study using videofluroscopy and manometry together, found that when different volumes which ranged from 2-15mL were introduced, no changes were observed in the extent of the hyoid or laryngeal displacement relative to the position of bolus head. The authors credited this to the temporal association between closure of larynx and bolus head flow remaining steady despite changes of laryngeal exposure time to the bolus as a function of volume.

The results of the Wilcoxon Signed Rank test (table 4.5) also revealed that there was a high significant difference ($p=0.01$) in terms of duration but, there was no significant difference in amplitude of hyolaryngeal excursion across viscosities at constant volumes of 5mL and at 10mL ($p > 0.05$). This indicated that on changing the viscosity, only the duration of hyolaryngeal excursion is significantly affected in both the bolus volumes.

Using various bolus viscosities, Lee, Sejdić, Steele and Chau (2008) using accelerometry, reported that swallow duration at the pharyngeal level could be significantly affected. Nectar and honey thick apple juices could yield longer durations of swallow on an average when compared to water and barium as seen in the present study. The same was reported by Reimers-Neils, Logemann, Larson (1994) and Dantas et al. (1990) using EMG and videofluroscopy, that when more viscous boluses were introduced, a longer duration of swallow was seen. This could be associated with longer time in the pharyngeal peristaltic waves and longer UES opening, which was attributed to the varying activity of muscles of hyolarynx. The authors also reported that the activity in the submental muscles most often initiated the swallow, whereas the infrahyoid muscle activity most frequently terminated the swallow and hence the activity of muscles varied with the change in the viscosity.

Notably, a study by Butler, Stuart, Castell, Russell, Koch, and Kemp (2009) reported smaller pharyngeal pressure on thicker boluses. They posited that as the weight of bolus is amplified, more gravity is required, in opposition to the pharyngeal driving force, than with thinner, less viscous boluses. Therefore, while swallowing thicker viscous boluses individuals might engage in less muscular force which will slower the transit time of the bolus, leading to heightened duration of pharyngeal swallowing.

With increase in viscosity, the mean duration and amplitude of the muscle activity were found to be increased (Van den Engel-Hoek, Groot, Esser, Gorissen et al., 2012) in young men and women as seen in this study. The study was also supported by Nagy et al. in 2015 who used cervical auscultation to track hyoid movements using different bolus consistencies and found that velocities were increased for nectar thick bolus than thin and ultra thin liquids in males, resulting in greater anterior hyoid movement.

Kim and McCullough (2009) also reported no significant differences in terms of vertical and anterior displacement of hyoid between male and female subjects. In another study by Youmans and Stierwalt (2010) reported no apparent differences between healthy male and female participants. Their study suggested that when the bolus viscosity is increased, the upward displacement of hyoid is also increased due to the propulsion pressure of the bolus and overall reduction in bolus velocity.

There was a significant difference only on certain measures at certain volumes/viscosities. This could be attributed to the ways in which men and women physiologically handle varying bolus volumes versus viscosities, or possibly it is the acoustic responses of their diversified anatomies to changing volumes versus viscosities.

b) With respect to clinical group

The values obtained in the clinical group were subjected to Wilcoxon Signed Ranks test across all the bolus volumes and bolus viscosities. The details of the findings are tabulated in the Table 4.6.

Table 4.6:

| z | and p values for different bolus volumes and viscosities for clinical group

Measures			/z/ value	p value
Water	Amplitude	5 ml vs. 10mL	2.49	0.01**
	Duration	5 ml vs. 10mL	2.34	0.01**
Curd	Amplitude	5 ml vs. 10mL	1.88	0.05*
	Duration	5 ml vs. 10mL	1.98	0.04*
5mL	Amplitude	Water vs. Curd	0.86	0.38
	Duration	Water vs. Curd	2.55	0.01**
10mL	Amplitude	Water vs. Curd	0.30	0.75
	Duration	Water vs. Curd	2.70	0.00**

Significant difference * $p < 0.05$ ** $p < 0.01$

The pattern of results obtained was similar to those obtained in the control group. There was no significant difference in the amplitude of hyolaryngeal excursion when thin liquid water and honey thick liquid curd were compared and introduced at 5mL and at 10mL ($p > 0.05$). However in all the other conditions there was a significant difference observed.

From Table 4.6, it can be seen that there was a high significant difference in terms of duration and amplitude of hyolaryngeal excursion at constant viscosities at varying volumes of 5mL and at 10mL. It can also be observed from Table 4.3 that the mean amplitude and mean duration increased slightly in the clinical group, when the volume of the bolus is increased. In contrast, Park et al. (2016) in a study found using VFSS that penetration or aspiration did not seem to be affected with the change in bolus volume of 2ml, 5ml and 10ml when barium thinned liquid was introduced. They only found a reduction in the pharyngeal delay time. It was also seen that with thin liquids, there was a greater significant difference across volumes in terms of amplitude ($p = 0.01$) and duration ($p = 0.01$) in comparison to thick liquids {amplitude ($p = 0.05$) and duration ($p = 0.04$)}.

From Table 4.6, it can also be seen that there was a high significant difference only in terms of duration and not in terms of amplitude of hyolaryngeal excursion at constant volumes of 5mL and at 10mL across viscosities. This indicated that on changing the viscosity only the duration of hyolaryngeal excursion is affected and no significant difference is seen based on amplitude of hyolaryngeal excursion.

Bisch et al. (1994) reported that increasing viscosity of bolus can result in increase in complete time span of swallow in post stroke survivors. Wu et al. (2018) also reported that when the bolus consistency is changed, the swallowing activity of muscles also changes in terms of duration. However, Choi, Ryu, Kim, Kang, and Yoo (2011) found that as the bolus viscosity increased, the extent of hyoid elevation is decreased.

Thus in post stroke survivors, it is ideal to provide a thicker viscosity bolus, as it has a significant impact on duration. Rofes, Arreola, Mukherjee, Swanson, and Clavé (2014) reported about the prevalence of aspiration with respect to different viscosities and found that prevalence of aspiration was 12.7% with thin liquid, 7.7% with nectar-like and 3.4% with spoon-thick viscosities thus supporting the findings of this study. Studies have reported that with the introduction of various viscosities the penetration and aspiration have decreased. Thicker liquids enhance the safety of swallowing and reduce the incidence of pneumonia. Thinner fluid consumption may increase the total fluid intake and hydration; however, they also increase the incidence of aspiration pneumonia.

Clave´ et al. (2008) reported that penetration into the laryngeal vestibule is a typical index of high risk swallowing and is very prevalent with liquid boluses and decreases with nectar and additionally a greater decrease is seen with pudding viscosity. In another study, Rofes, Arreola, and Clave´ (2012) also documented statistically significant results where they reported that when the bolus viscosity is increased from liquid to pudding, it automatically reduced the prevalence of penetration and aspiration in 98.9 % of patients. Using VFSS (Kuhlemeier, Palmer, & Rosenberg, 2001; Clave et al., 2006; Choi, Ryu, Kim, Kang, & Yoo, 2011; Leonard, White, McKenzie, & Belafsky, 2014; Rofes, Arreola, Mukherjee, & Clave´, 2014) and FEES (Diniz, Vanin, Xavier, & Parente, 2009; Leder, Judson, Sliwinski, & Madson, 2013) various authors have found that when high viscous boluses are introduced in contrast to thin boluses for stroke individuals, a significant reduction in the prevalence of aspiration was seen. These point to the usage of a thicker bolus for safe passage during swallow.

Effects of varied bolus viscosities and volumes on the timing of physiological events may have therapeutic implications in post stroke patients exhibiting changes in excursion of hyolarynx. Using thicker bolus will help in better management of post stroke individuals. There is some evidence that dietary modifications may reduce the incidence of aspiration pneumonia (Groher, 1987). Goulding and Bakheit (2000) using a viscometer, prepared thickened fluids for post stroke patients at an apt and safe consistency, resulting in an enhancement in nutritional outcomes. Hence, managing the post stroke individuals using different bolus volumes and viscosities are effective to help them recover and reduce the chances of aspiration and penetration, thus improving their swallowing and their overall quality of life.

To sum up, the results of the current study indicated that there was an overall difference seen across different bolus viscosities and bolus volumes. The Cronbach's alpha test was performed, it was found that values were greater than 0.90 indicating excellent test-retest reliability. The male participants of the control group had larger values of amplitude and duration when compared to female participants with various bolus viscosities and bolus volumes, however there was a significant difference only between the amplitude measure for 5ml water, 10ml water and 5ml curd and a between the duration measure for 5ml water. Post stroke survivors were found to have overall increased amplitude and durational values, when compared to neurotypical individuals with different bolus viscosities and bolus volumes, though significant differences were seen only in amplitude for thin liquid (5mL and 10mL) and in the duration measure for honey thick liquid. It was also found that at constant bolus viscosities and varying bolus volumes, a significant difference was found in terms of amplitude and duration of hyolaryngeal excursion in the control and clinical group. It was also found that at constant bolus volumes, and varying bolus viscosities, a high significant difference was found only in terms of duration of hyolaryngeal excursion in both the groups.

CHAPTER V

SUMMARY AND CONCLUSIONS

*S*troke is a life-threatening serious medical condition that arises the moment the blood supply is cut off or reduced to the brain which will directly influence the cells resulting in its death. This occurs either when the artery is blocked (ischemic stroke) or the blood vessel leak or burst out (hemorrhagic stroke). Stroke is found to be second most common cause of death and disability worldwide, affecting around 15 million people each year. In India, the incidence of stroke is much higher than Western industrialized countries. The estimated adjusted prevalence rate of stroke range from 84-262/1,00,000 in rural and 334-424/1,00,000 in urban areas. The incidence rate is 119-145/100,000 as per a recent population based investigation (Pandian & Sudhan, 2013). It is found to be one of the most leading causes of serious physical and linguistic disability.

Amidst these changes, dysphagia i.e. swallowing difficulties is also a high common sequel following stroke, affecting the oral, pharyngeal and esophageal phases, affecting 13–94% of persons with acute stroke, with the incidence depending on the site and size of lesion. Among the various problems encountered in the different phases of swallowing post stroke, changes in hyolaryngeal excursion during the pharyngeal phase of swallow and its assessment is significant since it contributes to the protection of the airway.

There are heterogeneous group of diagnostic procedures that exists for the assessment of hyolaryngeal excursion like VFSE, FEES, and Ultrasound, which have been used extensively, however other potential approaches using accelerometric principles have been less explored. Using accelerometry principles when the swallowing is modified by various types of food boluses by changing the viscosities and volumes, with their effects on accelerometry signals have never been thoroughly investigated. Keeping this in view, the current study has been planned to investigate the hyolaryngeal excursion using accelerometry signal characteristics to measure the amplitude and duration of the of hyolaryngeal elevation using different bolus volumes and bolus viscosities in post stroke survivors and neurotypical individuals. The specific objectives of the study were to investigate the durational and amplitude parameters of hyolaryngeal excursion during the swallow of two different bolus volumes and two different bolus viscosities in post stroke survivors and compare it with the neurotypical individuals.

With these objectives, two groups of participants were recruited for the study. In group I, a total of ten participants (9 males and 1 female) in the age range of 39 - 59 years were recruited for the study and they constituted the clinical group. Thirty neurotypical healthy individuals (15 males and 15 females) were included and considered as the control group for group II. All the participants were provided with two liquid bolus viscosities, thin liquid water and thick liquid curd at two bolus volumes, 5mL and 10mL. Digital accelerometry for swallowing imaging (DASI^{TM}, Elixir Research, USA) version L8.0 was used to track the movement of hyolaryngeal complex. In order to ensure test-retest reliability, 10% of the samples were randomly selected and reanalyzed, after one week of the first recording from both the group of participants.

From the recorded data, measures of interest amplitude and duration of the hyolaryngeal elevation for two different volumes and viscosities of liquid were derived. The values obtained from all the participants with respect to different protocols were totalled and averaged across all the participants. The data obtained was subjected to statistical analysis using SPSS software version.

The results of the current study indicated that there was an overall difference seen across different bolus viscosities and bolus volumes. The Cronbach's alpha test was performed, it was found that values were greater than 0.90 indicating excellent test-retest reliability. The male participants of the control group had larger values of amplitude and duration when compared to female participants with various bolus viscosities and bolus volumes, however there was a significant difference only between the amplitude measure for 5ml water, 10ml water and 5ml curd and a between the duration measure for 5ml water. Post stroke survivors were found to have overall increased amplitude and durational values, when compared to neurotypical individuals with different bolus viscosities and bolus volumes, though significant differences were seen only in amplitude for thin liquid (5mL and 10mL) and in the duration measure for honey thick liquid. It was also found that at constant bolus viscosities and varying bolus volumes, a significant difference was found in terms of amplitude and duration of hyolaryngeal excursion in the control and clinical group. It was also found that at constant bolus volumes, and varying bolus viscosities, a high significant difference was found only in terms of duration of hyolaryngeal excursion in both the groups. Thus it can be concluded that managing the post stroke individuals using different bolus volumes and viscosities are effective to help them recover and reduce the chances of aspiration and penetration thus improving their swallowing and their quality of life.

Clinical implications

This study provides an insight into the differences in the measures of hyolaryngeal excursion for different liquids of different viscosities and of different volumes. The information on the influence of bolus viscosity and volumes can be beneficial for the management of post stroke survivors with oropharyngeal dysphagia. Effects of varied bolus consistencies and volumes on the timing of physiological events may have therapeutic implications in post stroke patients exhibiting changes in excursion of hyolarynx.

The amplitude and the durational measures of hyolaryngeal movement during swallow obtained from the neurotypical individuals can be used as a basis for assessment and management. The data obtained can be used to monitor the success of the rehabilitation techniques used in the patients with dysaphagia. The results can also help in carrying out need based counselling with regard to swallowing difficulties in persons with stroke.

Limitations

The results obtained cannot be generalized to all stroke individuals due to a small sample size and the heterogeneous nature of post stroke survivors with respect to lesion site and size. The effect of gender in the post stroke survivors could not be investigated as there were no equal participants in the group.

There was a high variability in the measures of hyolaryngeal elevation of swallow across subjects. Measures of the hyolaryngeal elevation computed by a method like accelerometry, can possibly be affected by different individual-specific physical characteristics like height, presence and absence of laryngeal prominence, position of larynx, thickness of skin or presence of fat layers over larynx, relative force of swallow etc. No scalars or correction factors were available in regard to these mentioned characteristics which can probably affect the measured parameters.

Future directions

The current study was a preliminary attempt to understand the hyolaryngeal excursion in post stroke survivors. Hyolaryngeal excursion associated with swallowing is observed to be in two directions, i.e, superior and vertical. The current study makes use of single axial accelerometry, and hence the movement directions are not specified. To be specific, the present study used a piezoelectric sensor to record the movements of the larynx. As it is known, a piezoelectric sensor converts all movements into potential differences irrespective of the direction of movement, that is, either anterior or superior. Hence, it is difficult to delineate specific movements of larynx from the recorded waveforms. Replication of the study using dual-axis accelerometry is required to see whether similar results can be obtained. The result of the present study suggests the need for an in-depth analysis to study the changes with different bolus volumes and bolus viscosities.

Further research is needed to study the hyolaryngeal changes with other type of bolus viscosities, volumes in different age groups. Comparative studies between neurotypical individuals and different types of stroke individuals on a larger sample will provide better insight into the pattern of hyolaryngeal movement.

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APPENDIX I

<u>Consent Letter for Dissertation</u>

Title: Measures of Hyolaryngeal Excursion in Post stroke Survivors for Different Bolus Volumes and Viscosities

<u>Participant Information</u>

Participant's Name: Participant's Number:
Age/Gender: Date:
MMSE Score: EAT-10 Score:
SES Score:
Medical History:

Informed consent

I have been informed about the aims, objectives and the procedure of the study. I understand that I have a right to refuse to participate. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily/ for my ______________ to participate in this study.

I, ____, the undersigned, give my consent/ on behalf of my_______________________ to be a participant of this investigation.

Signature of the participant/Caregiver Signature of the Investigator
(Name and Address) Name:

Description of the study: The study aims at investigating the hyolaryngeal excursion in Post stroke Survivors for Different Bolus Volumes and Viscosities and measure the duration and amplitude of hyolaryngeal excursion during the swallowing and compare them with neurotypical individuals.

APPENDIX II

Consent Letter for Dissertation

Title: Measures of Hyolaryngeal Excursion in Post stroke Survivors for Different Bolus Volumes and Viscosities

Participant Information

Participant's Name: Participant's Number:
Age/Gender: Date of assessment:
Date and Type of Stroke: MMSE Score:
GUSS Score: Direct - Indirect -
Speech and Language therapy details: Swallowing difficulties if any:
SES Score:
Medical History and earlier investigations:

Informed consent

I have been informed about the aims, objectives and the procedure of the study. I understand that I have a right to refuse to participate. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily/ for my _______________ to participate in this study.

I, ____, the undersigned, give my consent/ on behalf of my_________________________ to be a participant of this investigation.

Signature of the participant/Caregiver Signature of the Investigator
(Name and Address) Name:

Description of the study: The study aims at investigating the hyolaryngeal excursion in Post stroke Survivors for Different Bolus Volumes and Viscosities and measure the duration and amplitude of hyolaryngeal excursion during the swallowing and compare them with neurotypical individuals.