A Descriptive study on the Video-Fluroscopic Measures of Neurogenic Dysphagia in Patients with Stroke and Motor Neuron Disease

ARF Project Report

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CHAPTER I

INTRODUCTION

Swallowing is one of the basic physiological functions required for survival. The process of swallowing is referred to as deglutition. Typically, deglutition is a coordinated process which is achieved through a series of complex combinations of voluntary and involuntary neuromuscular contractions. According to Logemann (1983), swallowing can be divided into four distinct phases, namely oral preparatory stage, oral stage, pharyngeal stage and esophageal stage. Problems at any of these levels can lead to difficulty in swallowing which is referred to as a condition called dysphagia. The American Gastroenterological Association (1999), refer to dysphagia as a condition and not a disease. The word 'dysphagia' is derived from the Greek words '*dys'* meaning 'bad or disordered' and '*phag'* meaning 'eat'. Dysphagia is defined as disordered movement of bolus from mouth to stomach due to abnormalities in structures critical to swallowing or in their movements during swallowing (Rosenbek & Jones, 2009). According to Schindler, Ginocchio and Ruoppolo (2008), the most common complications of dysphagia are aspiration pneumonia, malnutrition and dehydration along with other associated impairments in the social and emotional domains. Identification of dysphagia at an early stage becomes an important goal so as to reduce its impact on the person's quality of life with prevention of complications resulting from this condition as a primary goal in management (Schindler, Ginocchio & Ruoppolo, 2008).

The basic sub classifications of dysphagia are oro-pharyngeal dysphagia and esophageal dysphagia (Wolf, 1990). Oro-pharyngeal dysphagia is a condition wherein there is either a difficulty in initiating the swallowing process or transporting the bolus into the upper esophageal region, whereas esophageal dysphagia occurs when food or liquid stops, slows down or does not enter into the esophagus usually because of a blockage or weakness.

The type of dysphagia can vary with its etiology. Thecauses of dysphagia are many, ranging from degenerative neurological disorders such as Motor Neuron disease (MND), Parkinson's disease, Multiple Sclerosis etc., cerebro-vascular accidents, gastro-esophageal reflux disorders, esophagitis, tumor, psychogenic dysphagia and so on (Lazarus & Logemann, 1987).

On an estimate, approximately 300,000-600,000 people per year are affected by dysphagia due to neurologic disorders (ECRI Evidence-based Practice Center, 1999). A review of epidemiological studies in dysphagia suggests highest prevalence of this condition in stroke and neurodegenerative disorders including Parkinson's disease (PD) and Amyotropic Lateral Sclerosis (ALS). Prevalence of dysphagia in post stroke individuals ranges from 30-81% (Sala et al., 1998; Meng, Wang & Lien., 2000) while it is reported to be as high as 90 % in individuals with PD and ALS (Coates &Bakheit, 1997). High prevalence rate of dysphagia (35-82%) were also reported by Kalf, Swart, Bloem and Munneke (2011) in individuals with PD. Next in epidemiological sequence are persons with dementia (13-57%; Alagiakrishnan, Bhanji & Kurian, 2013), traumatic brain injury (38% –65%; Terre &Mearin, 2009) and multiple sclerosis (24%–34%; Calcagno, Ruoppolo, Grasso, De Vincentiis, &Paolucci, 2002; De Pauw, Dejaeger, D'Hooghe, & Carton, 2002; Roden& Altman, 2013). This suggests that though the prevalence estimates of dysphagia are variable across diagnostic labels, dysphagia is a common co morbidity following neurologic disorders especially stroke and MND.

Stroke is one of the leading causes of morbidity and mortality affecting millions of people worldwide every year (Kuruvilla, Thomas &Bharucha, 1998). Numerous studies have tried to establish the incidence of dysphagia after stroke. According to a study done by Sharma, Fletcher, Vassalo and Ross (2001) in consecutive ischemic and hemorrhagic strokes, the incidence rate of dysphagia following stroke was found to be 51%. Another epidemiological study reported an incidence as high as 76% (Schelp, Cola, Gatto, Silva & Carvalho, 2004). The variability in incidence of dysphagia following stroke could be related to various factors such as type of stroke, patient selection criteria, methods of dysphagia evaluation and also duration post-onset. Available reports suggest that the incidence of dysphagia is very high in the initial days post stroke but gradually resolves its severity over the following weeks. Hamdy et al. (1998) attempted to study the recovery of swallowing function after stroke in a time series study and found that the severity reduced by the third month post stroke. Return of swallowing function after a stroke was associated with increased pharyngeal representation in the unaffected hemisphere, suggesting the role of intact hemisphere reorganization in the recovery of this function. Hence, it is necessary that dysphagia screening be included in an individual's post stroke follow up consultations so that the earliest indication of a long-standing dysphagia could be detected and rehabilitation strategies could be implemented at the earliest. This will improve the person's overall functional level as well as quality of life (Kwok, Lo, Wong, Wai-Kwong, Mok,& Kai-Sing, 2006; Chen, Golub, Hapner,& Johns, 2009).

Yet another group of disorders where dysphagia remains as one of the major co-morbid problems is the group of Motor Neuron Disorders (MND). The bulbar onset variant of this condition results in an inability to initiate and control the movementsof muscles related to speech and swallowing and this is often one of the first symptoms of this condition (Hadjikoutis& Wiles, 2001). As a result, people with MND may lose ability to speak, eat, move and breathe. Dysphagia is prevalent in 30-100% of individuals with MND depending on type and stage of the disease, mostly affecting all individuals in the later stages of the disease (Walshe, 2014). Leighton, Burton, Lund and Cochrane (1994) studied the characteristics of swallowing problems in patients with MND and concluded that moderate or severe swallowing difficulty was present in 89% of patients who had presented with bulbar onset. Unlike in post stroke, the severity of dysphagia moves towards the higher with post onset duration (Waito, Valenzano, Peladeau-Pigeon, & Steele, 2017). Hence, the pathophysiology of these two conditions, stroke and MND, with co-morbid dysphagia follows their distinct course.

Though there have been plenty of researches on neurological dysphagia, scrutiny of the research focus suggest wide lacunae. Many of the published literature reports are confined to understanding the prevalence of dysphagia in specific types of neurological disorders (Marik, 2003; Gonzalez-Fernandez, Kuhlemeir, & Palmer, 2008; Falsetti, Acciai, Palilla, Bosi, Carpinteri, & Zingarelli, 2009; Takzawa, Gemmell, Kenworthy & Speyer, 2016). Few reports detail the symptom presentation (Johnston, Li, Castell & Castell, 1995; Kalia, 2003; Singh & Hamdy, 2006; Barichella, Cereda, Madio, Iorio, Pusani&Cancello, 2013) in these groups. Over the years, the approach towards the population with dysphagia has also changed. For example, earlier studies concerning post stroke dysphagia studied only a brainstem or bilateral supratentorial infarct (Daniels & Huckabee, 2014). However, further research has suggested that a single cortical or subcortical infarct could also result in similar symptoms (Daniels & Foundas, 1999; Robbins, Levine, Maser, Rosenbek & Kempster, 1993). Likewise, researches on MND are skewed towards understanding the risk factors of dysphagia and its predictors (Leighton, Burton, Lund & Cochrane, 1994; Walshe, 2014).

Another set of studies in neurological dysphagia explore the assessment and management options available for neurological dysphagia. These studies have attempted to arrive at various management options based on the clinical examination findings (Ott, Hodge, Pikna, Chen, & Gelfand, 1996; Perie, Wajeman, Vivant, & St Guily, 1999; Kidney, Alexander, Corr, O'Toole & Hardiman, 2004; Solazzo et al., 2014) and other instrumental evaluations such as Videofluroscopy (Robbins, Hamilton, Lof, &Kempster, 1992; Briani et al., 1998; Han, Paik, & Park, 1999, 2001; Chen, Chie, Lin, Chang, Wang & Lien, 2004; Bian, Choi, Kim, Han & Lee, 2009; Kawai et al., 2003; Terre &Mearin, 2006; Paris et al., 2013), Scintigraphy (Fattori et al., 2006; Silvia, Fabio & Dantas, 2008; Szacka et al., 2016) or Flexible Endoscopy (Leder, Novella, & Patwa, 2004; Shirazi, Buchel, Daun, Lenton, & Moussavi, 2012; Pluschinski, Zaretsky, Stöver, Murray, Sader, & Hey, 2016). Identification of predictors of aspiration pneumonia through screening procedures and objective evaluation has been a major focus of research over the years (Chong, Lieu, Sitoh, Meng &Leow, 2003; Hinchey, Shephard, Furie, Smith, Wang &Tonn, 2005; Martino et al., 2009). However, lack of a standardized protocol to objectify the impairments in these clinical examinations make generalization of findings across studies of neurological dysphagia unreliable.

A review of published literature on specific swallowing impairments in neurological dysphagia reported impaired oral and pharyngeal stage function (Kendall & Leonard, 2000; Ellerston, Heller, Houtz& Kendall, 2016; Kendall, Ellerston, Heller, Houtz, Zhang &Presson, 2016; Suttrup&Warnecke, 2016). These reports indicate major pharyngeal involvement than oral or esophageal involvement in individuals with neurological dysphagia. However, the oral stage involvement in these individuals cannot be neglected due to coexisting speech impairments. Co-existence of speech and swallowing impairments in persons with stroke and MND suggest that more than one stage of swallow may be impaired in these individuals. Also, the realization that swallowing is a complex series of timely coordinated contractions at various loci advocates that incoordination or impaired output in any of the previous loci may lead to an impaired output at later loci. Hence, it is necessary to have a holistic look at the swallowing physiology rather than viewing the entire process in stages. Hence, the reports of pharyngeal impairments in post stroke and MND group may be related to other impairments at a different locus. This has its implications in treatment planning and efficiency of rehabilitation approaches.

A detailed understanding of the impaired physiology in neurological dysphagia may help reveal patterns of impairment specific to the condition that the individual is diagnosed with and also identify if associations exist between swallow functions at the oral, pharyngeal and esophageal stages of swallow in neurological dysphagia. For example, affected hyo-laryngeal function could also be related to impairment of tongue function rather than suggesting pharyngeal stage impairment only. Identifying such patterns can help in designing appropriate dysphagia management strategies specific to a clinical population. Thus it becomes necessary to fill in some of the gaps identified in the literature on physiology of swallow in neurological dysphagia, especially the two leading causes of this condition- stroke and MND (Coates &Bakheit, 1997; Sala et al., 1998; Meng et al., 2000).

But this understanding is generally scarce with very few studies attempting to understand the pathophysiology specific to various functions related to stages of swallowing (Ertekin, Aydogdu, Yüceyar, Kiylioglu, Tarlaci&Uludag; 2000; Kawai et al, 2003) and its relation to aspiration pneumonia. This lacunae needs to be filled not just for enhancing our knowledge of most affected swallowing physiology, but also to aid in the dysphagia management and rehabilitation. In addition, limited attempts have been made to study the underlying physiology of swallow in persons with acquired neurologic conditions from an Indian scenario. It is still unclear, if the fewexisting findings in global literature are applicable to Indian swallowing systems. Superficially, the swallowing physiology may seem similar but the oro- sensory-motor experiences of Indian population differ from other parts of the world owing to the rich food culture. Therefore, the learned adaptations to sensory information can be suspected to differ across cultures. Thus, research on dysphagia in Indian scenario should start from basic research and not assume generalized evidences from published literature.

Need for the study

Knowledge of physiology is the foundation on which further information on factors, variables, quality of a function and its dysfunction is built upon, so that a health care professional can derive measures to objectively quantify and assess the function. With reference to swallowing function, considerable amount of work has been done for untangling the complex neuro-physiology of this function in typical individuals (Logemann, 1998;Daniel &Foundas, 2001; Arnold et al., 2016). The data derived from these studies have provided immense insight into the neuro-musculo-skeletal coordination with various intrinsic (Rademaker, Pauloski, Colangelo &Logemann, 1998; Cichero& Murdoch, 2002; Jalabert-Malbos, Mishellany-Dutour, Woda&Peyron, 2007;Butler, Stuart, Castell, Russell, Koch & Kemp, 2009; Youmans &Stierwalt, 2011) and extrinsic variables (Bisch, Logemann, Rademaker, Kahrilas& Lazarus, 1994; Cichero& Murdoch, 2002; Jalabert-Malbos, Mishellany-Dutour, Woda&Peyron, 2007; Butler, Stuart, Castell, Russell, Koch & Kemp, 2009; Youmans &Stierwalt, 2011). The output of research concerning typical swallow has been the template against which atypical function is compared for its efficiency and accuracy. However, to isolate and identify the cause of difference in swallowing function, one needs to re-look into the swallowing physiology in atypical population more meticulously.

A health care professional is often primarily provided with a set of symptoms that are reported by the person with dysphagia. These symptoms are frequently observed during clinical examination (Hinds & Wiles, 1998; Gallas, Marie, Leroi &Verin, 2010) or reported by the individual or their family members. The first step towards rehabilitation is to identify the deficit that leads to a reported symptom. For this purpose, the professionals rely on direct observation of the physiology through endoscopy or else imaging of the function through radiological procedures. A complete profiling of atypical physiology in each pathological condition can provide the professional with quick links to which the symptomscould be associated. This can improve the efficiency of clinical practice by reducing the need for detailed time consuming and often uneconomical diagnostic inventory. With a complete physiological profile, the sensitivity of screening protocols could be improved with elaborated evaluation on the most frequently impaired physiology.

All swallowing rehabilitation approaches are developed for specific physiological dysfunctions (Burkhead, Sapienz&Rosenbek, 2007; Huckabee &Doeltgen, 2007; Verin& Leroi, 2009). From the literature review, it could be observed that more than one physiology is frequently impaired in atypical neurological system (Logemann, Shanahan, Rademaker, Kahrilas, Lazar & Halper, 1993; Martin, Diamond, Aviv, Sacco, Keen & Blitzer, 1996; Paris et al, 2013; Rofes, Vilardell& Clave, 2013; Walshe, 2014). However, if one is aware of the cluster of deficits commonly found in each pathological condition, quicker clinical decisions related to development of a rehabilitation plan can be facilitated. Therefore, profiling of physiological dysfunctions in specific atypical swallowing groups also help a professional to design the most effective rehabilitative plan using compensatory or skill learning strategies. Pre-designed population specific rehabilitation strategies can facilitate faster clinical decision and quicker client progress in their swallow function.

Studies from typical swallow physiology suggest that though dividing the swallow function into stages is appropriate for theoretical purposes, in practice these divisions are arbitrary. A sequential dependence of swallowing functions is observed during the actual performance with the accuracy of functions at a later stage of swallow being dependent on the functions in a previous stage of swallow. The reports in literature that multiple deficits leading to symptoms of dysphagia in persons post stroke and MND can be explained if the root cause of these deviations are identified and treated. Developing strategies for treatment of the root cause may adjust the function of other related physiological functions thereby improving the efficiency of treatment regimens. This requires a complete profiling and investigations that question the association or dissociation of physiological functions in atypical neuro systems. Existing studies in this regard are scarce though hinted decades ago (Roller, Garfunkel, Nichols, & Ship, 1974; Carpenter III, McDonald, & Howard, 1978; Martin, Diamond, Aviv, Sacco, Keen & Blitzer, 1996; Micklefield, Jorgensen, Blaeser, Jorg&Kobberrling, 1999; Ertekin, Aydogdu, Yüceyar, Kiylioglu, Tarlaci&Uludag, 2000; Bian, Choi, Kim, Han & Lee, 2009)

Typical swallowing physiology adapts itself through real time integration of sensory information into the pre-programmed swallowing sequence (Bult, De Wijk& Hummel, 2007). With a neurological insult, it is fairly established that this integration and adaptations are toppled. This is also said to be causative factor for laryngeal penetration and aspiration in PsWD. Literature review revealed very few studies that have compared the effect of sensory variables on atypical swallowing physiology (Vilardell, Rofes, Arreola, Speyer & Clave, 2016). The many other oro-pharyngo-laryngo-esophageal functions that do or fail to adapt and integrate the sensory inputs from swallowing system are less understood. This information can be helpful in incorporating bolus modifications for facilitating safe and efficient swallow in PsWD. Hence the preexisting lacunar in research includes: -

1. Studies in literature are skewed towards identification of symptoms (Briani et al., 1998; Martino, Foley, Bhogal, Diamant, Speechley, &Teasell, 2005; Crary, Mann, &Groher, 2005; Singh &Hamdy, 2006), functional level predictors (Warms & Richards, 2000; Daniels, Ballo, Mahoney &Foundas, 2000; Hadjikoutis& Wiles, 2001), methods of identification (Martino, Foley, Bhogal, Diamant, Speechley, &Teasell, 2005;Worwood, & Leigh, 1998) and approaches to management (Hefferman et al., 2004; Shaker & Geenen, 2011) of dysphagia in persons with stroke or MND. Understanding and detangling the complex pathophysiology of dysphagia in these two atypical neuro systems is relatively less attempted.

2. The variability across published research that study physiological alterations in persons with stroke or MND during swallow are incomparable due to non-uniformityin the variables considered (Plant, 1998; Singh &Hamdy, 2006; Waito, Valenzano, Peladeau-Pigeon, & Steele, 2017), methods used to study the swallowing physiology (Kawai et al., 2003; Paris et al., 2013; Solazzo et al., 2014; Leder, Novella, & Patwa, 2004) and also their outcomes.
3. Few studies that have worked towards this direction have studied only the pharyngeal stage of swallowing and have reported number of dysfunctions in this stage of swallowing in post stroke and MND (Carpenter et al., 1978; Roller et al., 1974, Seo, Oh, & Han, 2015). These findings may be better explained if its association or dissociation between other related physiological functions during swallow is also explored because swallowing is a series of movements that result in one output and not one or more isolated movements (Silvia, Fabio &Dantas, 2008; Walshe, 2014).
4. Though it is unanimously accepted that swallow physiology depends on various bolus characteristics, it is the volume that continues as the most frequently studied variable (Bisch, Logemann, Rademaker, Kahrilas& Lazarus; 1994; Hadjikoutis, Pickersgill, Dawson &Wiles 2000; Steele et al., 2015). Physiology modifications across bolus consistencies in atypical groups such as stroke and MND are not frequently cited as topics of research. It is also to be noted that in routine activities, these two variables interact with each other and hence, future research should also be directed towards probing this interaction.
5. Video-fluroscopy is considered as the gold standard for swallowing evaluation though concerns about radiation hazards have been prevailing over the years. Obtaining as much information within the optimum period of radiation exposure is a challenge to

the dysphagia clinician. This calls for recording protocols specific to the diagnostic group being evaluated for dysphagia.

Preceding remarks concerning the lacunae in literature on atypical swallowing physiology is most unfavorable for post stroke and MND population, as the epidemiological data suggested that the prevalence of this condition was highest in this group. Most of the studies included physiology of only oral (Kawai et al, 2003; Silvia, Fabio &Dantas, 2008; Walshe, 2014) or pharyngeal (Martin, Diamond, Aviv, Sacco, Keen & Blitzer, 1996; Ertekin, Aydogdu, Yüceyar, Kiylioglu, Tarlaci&Uludag, 2000; Seo, Oh, & Han, 2015), or esophageal (Weber et al., 1991; Micklefield, Jorgensen, Blaeser, Jorg & Kobberrling, 1999; Fattori et al., 2006; Szacka et al., 2016) functions. Few researchers randomly studied selected oro-pharyngeal functions of swallow (Roller et al., 1974; Carpenter et al., 1978; Terre & Mearin, 2006; Rofes, Vilardell & Clave, 2013). There were no studies in published scientific literature on these individuals that included all physiological functions from lip to stomach from the three stages of swallowing, leading to incomplete profile of these functions. Being a common service seeker at dysphagia clinics, incomplete understanding of their difficulties hinders with effective as well as efficient treatment planning and rehabilitation. Hence, future research should focus on understanding the physiological functions at all stages of swallowing that does or does not contribute to dysphagia symptoms in post stroke and MND population. It is also important that the response of these swallowing functions to various intrinsic and extrinsic factors be documented for the aforementioned reasons.

The present study was planned to derive a complete profile of swallow physiology in persons with dysphagia post stroke and MND. Most of the studies in this regard, use radiological imaging procedure of VFSS (Briani et al., 1998; Chen, Chie, Lin, Chang, Wang & Lien, 2004; Han, Paik, & Park, 1999, 2001; Robbins, Hamilton, Lof, & Kempster, 1992; Kawai et al., 2003; Terre & Mearin, 2006; Bian, Choi, Kim, Han & Lee, 2009; Paris et al.,

2013) and is considered the gold standard in dysphagia diagnostics. Many other direct investigation procedures such as FEES are being validated and are gaining substantial popularity among practitioners but have its limitations with respect to stages of swallow that can be visualized during the performance of a swallow function. Therefore, a study aiming at profiling the swallow function and its response to variables should essentially use VFSS as a primary source of data. The period of radiological exposure is a main concern while including VFSS for research purpose (Beck &Gayler, 1990; Zammit-Maempel, Chapple & Leslie, 2007; Kim, Choi & Kim, 2013). However, validated protocols, like MBSImp™, provide the professionals with methods of obtaining maximum data within the safe exposure period. Also, this protocol provides the trained professionals with the scope of assessing a wide number of physiological functions across various bolus characteristics such as consistency and volume.Therefore, apart from the primary aim of profiling the swallow physiology at oral, pharyngeal and esophageal stages of swallow using VFSS recordings obtained with MBSImp™ protocol, the study also compared the differences in performance of swallowing function at the three phases across different bolus consistency. The output of the current research is expected to provide a comprehensive and strong basement on swallowing function post stroke and MND. The information would be useful for theoretical knowledge and for clinical decision making when dealing with persons with dysphagia secondary to these diagnoses.

Aim of the study

The primary aim of this study was to score and profile the various physiological components of oral, pharyngeal and esophageal phases of swallow using Video-Fluroscopic Swallowing Study in post stroke individuals with persistent dysphagia and individuals diagnosed with Motor Neuron Disease. The study also aimed at understanding the changes in swallowing physiology across bolus consistency changes in and across these two neuro-atypical groups.

Objectives of the study

1. To score and profile the oral, pharyngeal and esophageal physiology during swallow of five bolus consistencies in post stroke and MND population with dysphagia using the Modified Barium Swallow Impairment Profile ($MBSImp^{TM}$).
2. To compare the oral, pharyngeal and esophageal impairment component scores in each consistency across the two groups (Stroke & MND).
3. To compare the oral, pharyngeal and esophageal component impairment scores across five bolus consistencies (Thin, Nectar-thick, Honey thick, Pudding and Solid) in the two groups (Stroke & MND).

Null hypothesis made for the study

Null Hypothesis 1: There is no significant difference in the Modified Barium Swallow Impairment Profile ($MBSImp^{TM}$) scores across the five bolus consistencies in post stroke and MND Population with dysphagia.

Null hypothesis 2: There is no significant difference in the Modified Barium Swallow Impairment Profile ($MBSImp^{TM}$) scores in the five bolus consistencies across post stroke and MND Population with dysphagia.

Null hypothesis 3: There is no significant difference in the Modified Barium Swallow Impairment Profile ($MBSImp^{TM}$) scores in the post stroke and MND Population with dysphagia across the five bolus consistencies.

CHAPTER II

REVIEW OF LITERATURE

The most common cause of dysphagia is known to be a cerebro-vascular accident (CVA) commonly called a stroke. Numerous studies have tried to establish the incidence of dysphagia post stroke. A wide range of incidence, 39 – 81 % (Palmer, 1991; Buchholz, 1994; Meng, Wang & Lien, 2000; Sharma, Fletcher, Vassalo & Ross, 2001; Parker, Power, Hamdy, Bowen, Tyrrell & Thompson, 2004; Schelp, Cola, Gatto, Silva & Carvalho, 2004; Terre & Mearin, 2006; Rofes, Vilardell & Clave, 2013; Arnold et al., 2016), has been reported in this population. This variability in post stroke literature is attributed to differences in type (Sharma, Fletcher, Vassalo & Ross, 2001; Aydogdu, Ertekin, Tarlaci, Turman, Kiylioglu & Secil, 2000; Teasell, Foley, Fisher & Finestone, 2002;Parker et al., 2004), loci (Arnold et al., 2016; Meng, Wang & Lien, 2000), duration post stroke (Gorden, Hewer & Wade, 1987; DePippo, Holas & Reding, 1994; Schelp, Cola, Gatto, Silvia & Carvalho, 2004), evaluation methods used (Briani et al., 1998; Meng, Wang & Lien, 2000; Silvia, Fabio & Dantas, 2008; Stöver, Murray, Sader, & Hey, 2016) and also other participant related variables (Martin, Logemann, Shaker & Dodds, 1994; Hiss, Treole & Stuart, 2001). Persistent dysphagia is most common in brainstem strokes with a prevalence rate of 81% at the end of three months post stroke (Meng, Wang &Lien, 2000). Based on the type of stroke, the prevalence ranges from 39-51% in ischemic and hemorrhagic strokes (Sharma, Fletcher, Vassalo & Ross, 2001; Parker et al., 2004). Irrespective of the variables considered, the presence of dysphagia in post stroke population is established across literature.

The next in line of causes is the genre of degenerative neurological disorders collectively referred to as Motor Neuron Disease (MND). Review of literature in this population revealed that the prevalence of oro-pharyngeal dysphagia ranges from 30- 100%

depending on the type and stage of the MND (Walshe, 2014). The diagnostic label of MND is preferred in the initial diagnostic sessions till a differential diagnosis can be established based on further symptom presentations, symptom progression and findings in the medical imaging technology. Several factors have complicated epidemiological studies in MND, including differential diagnosis, varied course of symptom progression, determination of an exact date of onset and the long interval between onset and clinical symptom manifestation. Generally, swallowing problems in MND are caused by weak muscles in the bulbar region affecting the face, mouth, tongue and throat. In individuals whose first symptoms affect this region (bulbar-onset) usually experience dysphagia at an earlier stage than those with other types of MND. Leighton, Burton, Lund and Cochrane (1994) studied the evidences for swallowing problems in ninety two patients with MND and concluded that moderate or severe swallowing difficulty was present in 89% of those whose had presented with bulbar onset disorder.

Though it is known that dysphagia is a common co-morbidity in a large proportion of individuals diagnosed with stroke or MND, the understanding of the exact physiological functions that are altered in these groups remain incomplete due to the very many variables that interplay with the swallowing process. Review of literature for the present study focused on reports that studied specific oral, pharyngeal and esophageal functions that are reported to be intact or impaired in persons diagnosed with stroke or MND. For the purpose of this review, MND referred to the group of neuro-degenerative disorders including bulbar onset MND and Amyotropic lateral sclerosis (ALS). The observations derived from this detailed review are summarized under the following section heads:

1. Review on Post Stroke Swallowing Physiology

    1.1. Oral, Pharyngeal and Esophageal Swallow Physiology in Post Stroke

    1.2. Variables studied in post stroke swallowing physiology

2. Review on Swallowing physiology in MND

   2.1.Oral, Pharyngeal and Esophageal Swallow Physiology in MND

   2.2.Variables studied in swallowing physiology of MND

3. Instrumentation for studying the swallowing physiology

Review on Post Stroke Swallowing Physiology

Oral, Pharyngeal and Esophageal Swallow Physiology in Post Stroke.

Co-morbid dysarthria in post stroke population is commonly attributed to the oro-sensory motor deficits in these individuals (Terre & Mearin, 2006; Rofes, Vilardell & Clave, 2013). Oro-sensory-motor function also plays a vital role in bolus preparation and propagation to the pharyngeal cavity during swallow. Hence, it is logical to probe into this function during a swallow evaluation in persons post stroke. The study by Terre and Mearin (2006) support this notion with their finding that among 138 number of participants with post stroke dysphagia, 39% of them had difficulty in tongue control, 20% of them had piece meal deglutition as well as reduced palatoglossal closure effecting 27% of the population to have increased oral transit time (OTT).

When compared to neuro-typical individuals OTT was longer in persons with stroke of basal ganglia (Logemann, Shanahan, Rademaker, Kahrilas, Lazar &Halper, 1993).Bolus characteristics (volume and consistency) also interplay and modify the bolus transit time through the swallowing system. Logemann et al. (1993) studied the transit times in patients with stroke and non-stroke subjects by administering liquid bolus of 1, 3, 5 and 10ml. The results of this study suggested an increase in OTT and decrease in pharyngeal transit time (PTT) with bolus volume. Similar findings were reported by Robbins and Levine (1988) and also Robbins et al. (1993). With bolus consistency, OTT was comparable to that of neuro-typical individuals for 5ml liquid bolus but longer for 5ml paste bolus indicating a direct relation between OTT and bolus consistency (Silvia, Fabio & Dantas, 2008). Another functional outcome usually considered in oral stage dysphagia is the amount of oral residue which is frequently found to be higher in post stroke population (Silvia, Fabio & Dantas, 2008).

Physiological weakness of lips in post stroke is a common symptom reported and is observed by professionals as anterior spillage (Kumar et al, 2012). Daniels, Brailey, Priestly, Herrington, Weisberg and Foundas, (1998) found that anterior bolus spillage was common among the 55 patients included in their study. Chewing abilities were also studied in oral stage dysphagia and was frequently reported to be impaired in post stroke dysphagia (Westergren, Karlsson, Andersson, Ohlsson, & Hallberg, 2001; Perry & McLaren, 2003; Westergan, 2006). Lingual coordination during swallowing is one measure that has been well characterized in the published literature (Daniels, Brailey & Foundas, 1999; González-Fernández, Ottenstein, Atanelov, & Christian, 2013). Random disorganization of the anterior and the posterior tongue movements are attributed to lingual incoordination in individuals with dysphagia post stroke (Daniels, Brailey & Foundas, 1999).

The transition from oral stage to pharyngeal stage of swallow, called the stage transition duration (STD), was found to be different in post stroke survivors with and without dysphagia with significantly long transition duration in aspirators (Kim & McCollogh, 2007). This duration was also found to predict aspiration 75% of the time in stroke survivors. Pharyngeal stage deficits at various loci in post stroke dysphagia result in increased pharyngeal transit time (PTT) (Silvia, Fabio &Dantas, 2008) and pharyngeal residue in 11% of post stroke dysphagia population (Terre &Mearin, 2006) when compared to neuro-typical individuals during swallow of thick bolus consistency (Bingjie, Tong, Xinting, Jianmin & Guijun, 2010; Silvia, Fabio &Dantas, 2008; Power, Hamdy, Singh, Tyrrell, Turnbull, & Thompson, 2007).

At the pharyngeal level, greater number of physiological functions has been reported to be impaired in stroke population. Somasundaram's (2014) study found that abnormal gag reflex was one among the most common deviation in swallowing function at the level of pharynx and was most frequently associated with an absent or abnormal cough reflex after swallow in persons with post stroke dysphagia. Approximately 3% of post stroke individuals had naso-pharyngeal penetration indicating velo-pharyngeal deficiency (Terre &Mearin, 2006). Compared to neuro-typical pharyngeal swallows, post stroke swallow had longer delay but shorter response time (Bisch, Logemann, Rademaker, Kahrilas & Lazarus, 1994). A delay in triggering of swallow reflex was also reported by Bingjie, Tong, Xinting, Jianmin and Guijun (2010) and in their study of post stroke dysphagia which also found a positive correlation between delay in reflex triggering and penetration aspiration score. Penetration and aspiration of bolus is a serious safety concern in 48- 66 % of individuals post stroke when oral feeding is to be continued. The episodes of laryngeal penetration may be related to incomplete epiglottic inversion (Seo, Oh, & Han, 2015), incomplete or shorter laryngeal vestibular closure (Bisch, Logemann, Rademaker, Kahrilas & Lazarus, 1994; Terre & Mearin, 2006), reduced magnitude of anterio-superior hyo-laryngeal movements (Bingjie, Tong, Xinting, Jianmin & Guijun, 2010), slower excursion velocity (Seo, Oh & Han, 2015) or a delay in initiating of hyo-laryngeal excursion (Power et al., 2007). Some of these findings are refuted with other studies conducted parallel. Anterio-superior hyolaryngeal movement, epiglottic inversion (Kim & McCollough, 2010) and laryngeal vestibular closure time (Power et al., 2007) were not significantly different across persons with and without aspiration post stroke. Measures of hyo-laryngeal elevation were found to predict aspiration in this population (Power et al., 2007; Power, Hamdy, Goulermas, Tyrrell, Turnbull & Thompson, 2009; Bingjie, Tong, Xinting, Jianmin & Guijun, 2010).

Apart from the motoric deficits in the pharyngeal structures of swallow, literature review also revealed presence of sensory deficits at the laryngopharynx in post stroke survivors. Significantly higher incidence of unilateral or bilateral sensory deficits may be one of the prime suspects for approximately 50% of post stroke survivors to be diagnosed as silent aspirators (Martin, Diamond, Aviv, Sacco, Keen & Blitzer, 1996). This cautions a dysphagia therapist to ensure thorough instrumental evaluation protocols that are sensitive towards detecting unprotected airway during swallow.

As the most feared complication of dysphagia is aspiration pneumonia, deficits till the laryngo-pharyngeal area is studied more in detail compared to esophageal deficits. Though limited attempts are made to study this phase of swallow in post stroke dysphagia, existing studies reveal that approximately 11% of post stroke population have upper-esophagus sphincter (UES) dysfunction (Terre & Mearin, 2006). Timely relaxation of the UES is vital for smooth transition from pharyngeal to esophageal stage of swallow. A UES dysfunction can result in pooling and pharyngeal residue that when associated with an unprotected airway may lead to aspiration after swallow. Impaired UES function in stroke survivors have been evidenced with the finding of multiple attempts in clearing the bolus from the pharyngeal area (Bisch et al., 1994; Bian, Choi, Kim, Han & Lee, 2009). Although UES was found to have a significant resting tone, it failed to relax and contract in coordination with the swallow reflex (Martino, Terrault, Ezerzer, Mikulis, &

Diamant, 2001; Bian, Choi, Kim, Han & Lee, 2009). Distally, atypical function has been reported in this population in terms of peristaltic contraction velocity, duration of contraction, and number of aperistaltic contractions (Weber et al., 1991; Micklefield, Jorgensen, Blaeser, Jorg & Kobberrling, 1999). Altogether, these differences in esophageal function are capable of altering the duration of esophageal transit (Silvia, Fabio & Dantas, 2008)but in mild presentation, may not be associated with dysphagia symptoms per se. However, an extensive research in this regard is not found in literature.

Variables studied in post stroke swallowing physiology

Normal physiology of swallow is known to vary with numerous intrinsic and extrinsic variables not to mention the subjective variations across swallows in the same individual. Research has established adaptation of typical swallowing physiology across age (Rademaker, Pauloski, Colangelo & Logemann, 1998; Cichero & Murdoch, 2002;Jalabert-Malbos, Mishellany-Dutour, Woda & Peyron, 2007;Butler, Stuart, Castell, Russell, Koch & Kemp, 2009; Youmans &Stierwalt, 2011), gender (Rademaker, Pauloski, Colangelo &Logemann, 1998; Butler, Stuart, Castell, Russell, Koch & Kemp, 2009; Cichero & Murdoch, 2002;Youmans &Stierwalt, 2011), bolus volume (Logemann, 1998; Cichero& Murdoch, 2002; Youmans &Stierwalt, 2011; Rademaker, Pauloski, Colangelo & Steele et al, 2015), bolus consistency (Youmans & Stierwalt, 2011; Steele et al, 2015), bolus texture (Jalabert-Malbos, Mishellany-Dutour, Woda & Peyron, 2007; Robbins et.al., 2007; Butler, Stuart, Castell, Russell, Koch & Kemp, 2009), bolus temperature (Bisch et al., 1994; Cola, Gatto, Silva, Spadotto, Schelp, & Henry, 2010), taste (Steele et al, 2015), mode of presentation (Kuhlemeier, Palmer &Rosenberg, 2001),posture (Rasley, Logemann, Kahrilas, Rademaker, Pauloski, &Dodds, 1993; Crary, 1995) and many other variables including psychological state and time constraints (Teasell, Bach & McRae, 1994). Many of these variables are less considered when it comes to swallowing physiology in post stroke dysphagia though bolus and diet modifications are gaining attention as one of the key management strategies in post stroke dysphagia rehabilitation (Bisch et al., 1994; Chi-Fishman &Sonies, 2002; Steele et al., 2015). Among the very few variables studied in post stroke dysphagia are bolus volume (Lazarus et al., 1993; Terre &Mearin, 2006), bolus viscosity (Lazarus et al., 1993; Han, Paik & Park, 2001), bolus temperature (Bisch et al., 1994; Cola et al., 2010) and bolus texture modifications (Bisch et al., Steele & Van Lieshout, 2004; Troche, Sapienza & Rosenbeck, 2008; Steele et al., 2015).

Adaptation to bolus volumes are also seen at the hyo-laryngeal level with longer duration of elevation thereby relaxing the UES for a longer duration (Lazarus et al., 1993; Han, Paik & Park, 2001).However, these reports are objected by the findings of Bisch et al. (1994) who found that post stroke individuals failed to show an increase in duration of airway closure with increased bolus volume though other measures such as pharyngeal reflex delay and duration of tongue base to posterior pharyngeal wall contact was reduced. Effect of bolus volume on triggering pharyngeal reflex is also supported by previous findings of Kahrilas et al. (1989), Logemann et al. (1992) and Lazarus et al. (1993). Findings of Bisch et al. (1994) suggests that increasing bolus volume could place an individual with post stroke dysphagia under risk of aspiration due to these maladaptation found at the laryngeal level.

Increased bolus viscosity has shown to prolong oral and pharyngeal transit time in post stroke swallow (Logemann et al., 1992; Lazarus et al., 1993). Pharyngeal delay is also reported to be longer with increased bolus viscosity in basal ganglia stroke (Lazarus et al., 1993). But, a closely followed study by Bisch et al. (1994) found that pharyngeal delay was shortened with increased bolus viscosity hence proposing equivocal findings. While increased volume decreased tongue base to pharyngeal wall contact, bolus viscosity modifications increased this measure (Lazarus et al., 1993). The duration of UES opening was also found to be longer in with increased bolus viscosity. Overall efficiency of oro-pharyngeal swallow is hence lesser with viscous bolus in post stroke. This is in contradiction with the findings of another group of studies in heterogeneous group of neurologic dysphagia that found thicker boluses safer than thinner ones as they move slowly through the oro-pharyngeal system hence providing more time for the person to adjust their swallowing system (Kuhlemeier, Palmer & Rosenberg,2001; Clave, Arreola, Romea, Medina, Palomera& Serra-Prat,2008; Bingjie, Tong, Xinting, Jianmin & Guijun, 2010).

Other bolus variables such as temperature and texture are among the least considered variables in physiological studies in post stroke dysphagia. Unlike typical individuals, temperature of the bolus was shown to have no effect on pharyngeal swallow measures in individuals post stroke (Bisch et al., 1994). However, small volume of cold liquid bolus was found to reduce pharyngeal delay time in mild dysphagics, probably because the cold temperature improved the sensory input in the oral cavity.This suggests a deviation in sensory analysis and integration into the motor algorithm of swallow in post stroke population. Therefore, there is a dearth of research on physiological adaptations to bolus texture modifications in post stroke dysphagia.

The above review on swallowing physiology in post stroke individuals with dysphagia suggests that a complete profile of physiological function changes in these individuals is yet to be derived. Considering the large number of variables that are related to swallowing and stroke, studies available in literature are enough to derive any conclusion. Therefore, more detailed research is required to understand the physiological adaptations brought in neuro-atypical system such as that of individuals with stroke.

Review on Swallowing Physiology in MND

Oral, Pharyngeal and Esophageal Swallow Physiology in MND

Irrespective of the type of MND, swallowing difficulties originate from weakness of muscles of the bulbar region resulting in oral and pharyngeal dysphagia. Therefore, oro-pharyngeal dysphagia is most reported as well as researched in this clinical population (Briani et al., 1998; Fattori et al., 2006; Paris et al., 2013). The impact of oro-pharyngeal dysphagia in the daily activities and quality of life of individuals with MND has also been a topic of research and is found that it has a direct impact on the psychological and social health of the individual (Paris et al., 2013). A comprehensive study of the physiological deficits at the oro-pharyngeal stage of swallowing by Walshe (2014) listed the inefficiencies in this population.The earliest inefficiencies appeared in the oral stage with the most frequent deficit being poor lip closure, poor lingual control, reduced and inefficient bolus mastication, manipulation and transport. Consequently, a delay in bolus transit could be noted which further led to prolonged OTT (Clave et al., 2006; Fattori et al., 2006; Walshe, 2014). Also, the magnitude of OTT was proportional to severity of MND (Fattori et al., 2006). Another measure of oral stage efficiency, the oral residue, was higher in persons with dysphagia secondary to MND (Clave et al., 2006; Fattori et.al., 2006; Walshe, 2014). Lingual function in MND was studied quantitatively in a small group of individuals with MND by Kawai et al. (2003). This study concluded that the oral phase deficits commonly reported in this population could mostly be attributed to difficulty in bolus transport by the anterior tongue or due to difficulty in bolus hold by the posterior tongue. This study emphasized that the poor lingual function plays a significant role in symptoms of dysphagia secondary to MND and is the core reason for inefficient oral preparatory and oral stages of swallow. This is also supported by the electromyographic studies of the submental muscle group which suggested a significantly longer muscle activity during swallow in individuals with MND when compared against age matched typical individuals (Ertekin, Aydogdu, Yüceyar, Kiylioglu, Tarlaci & Uludag, 2000).Higo, Tayama, Watanable and Nitou (2002) found that initial manometric changes appear in the oro-pharyngeal region followed by hypopharynx within a period of 1 year.

Compared to the oral phase, pharyngeal phase dysfunctions are less studied in individuals with MND. Naso-pharygeal penetration, delayed pharyngeal reflex trigger, and reduced as well as longer hyo-laryngeal excursion were reported to be the most common physiological deviations in persons with MND (Ertekin et al., 2000). This is supported with similar findings in persons with ALS that found a delay in triggering of pharyngeal reflex (Clave et al., 2006). Pharyngeal deficits are also indicated by the reduced amplitude and increased contraction time in MND compared to matched control group (Ellerston, Heller, Houtz& Kendall, 2016; Solazzo et al., 2016). The same may be inferred from the manometric studies of Kawai et al. (2003) that reported reduced magnitude of hypo-pharyngeal pressure in MND population. As a result of these deficits, a greater proportion of swallowed bolus remains in the pharyngeal pockets such as valleculae (Argolo, Sampaio, Pinho, Melo &Nobrega, 2015; Clave et al., 2006; Leighton, Burton, Lund & Cochrane, 1994; Wright & Jordan, 1997) and neo-pharynx (Argolo et al., 2015). This residue may be often aspirated after swallow clinically observed as symptoms of aspiration/penetration post swallow.

Along with the findings of pharyngeal weakness, prevailing reports question the coordination of pharyngo-laryngeal functions that ensure swallowing safety in individuals with MND. The laryngeal response to swallowing reflex initiation was reported to be delayed in this population leaving an open airway at the time of bolus propulsion through the pharynx (Kawai et al., 2003; Clave et al., 2006; Ellerston, Heller, Houtz & Kendall, 2016). Submental electromyography of laryngeal elevator muscle potentials are significantly prolonged (Ertekin,Aydogdu, Yuceyar, Kiylioglu, Tarlaci, &Uludag, 2000) indicating slower hyo-laryngeal elevation for airway closure. Weak and in-coordinated pharyngeal functions precluded by oral stage inefficiencies prolong the pharyngeal transit time significantly in persons with dysphagia following MND (Fattori et al, 2006). The coordination between hyo-laryngeal elevation and UES opening also plays a vital role in performing a safe swallow and this was impaired in individuals with MND (Leighton, Burton, Lund & Cochrane, 1994; Ertekin et al, 2000; Argolo et al., 2015; Ellerston, Heller, Houtz & Kendall, 2016).

Though it appear in the later stages, hypertonic and hyper-reflexive UES is a trait of pharyngeal dysphagia in persons with MND (Higo, Tayama, Watanabe & Nitou, 2002).The electromyographic investigation of this structure revealed random outbursts of motor unit potential along with untimely contraction and relaxation in MND. The UES opening was delayed or otherwise closed prematurely in persons with ALS (Ertekin et al., 2000). Manometry at the hypopharynx revealed that the residual pressure at the UES was higher in MND compared to control group indicating incomplete UES relaxation during swallow (Solazzo et al., 2016). Similar findings were also reported in PD and ALS population by Argolo et al. (2015) and

Ertekin et al.(2000) respectively. They found untimely as well as incomplete relaxation of UES during swallow in the clinical population studied and its activity predicted penetration/ aspiration along with piece meal deglutition and pharyngeal residue (Briani et al., 1998; Ertekin et al., 2000; Argolo et al., 2015).

There is a dearth of studies of esophageal function in persons with dysphagia secondary to MND. Among the very few studied in this direction, findings are equivocal with some suggesting the presence of it (Roeder, Murray & Dierkhising, 2004;Fattori et al, 2006; Szacka et al, 2016) and few suggesting otherwise (Briani et al, 1998; Kawai et al., 2003). Scintigraphy examinations conducted by Szacka et al. (2016) revealed that more than 80 % of individuals with MND had esophageal dysphagia. Longer esophageal transit time in persons with MND is reported in literature compared to normal age matched control group (Fattori et al., 2006; Szacka et al., 2016). Attempts to correlate these impairments with the severity and stage of MND were non-significant statistically (Fattori et al., 2006).

To summarize, there are no sufficient information yet available on the swallowing physiology impairments in persons with MND. The oral phase is relatively better understood while the later stages are almost neglected. The understanding of impairment cluster is important in designing the most appropriate rehabilitative strategy for persons with dysphagia secondary to MND.

Variables Considered in Studies of Swallowing Physiology in MND

The present review of studies on physiological deficits in persons with MND suggested fewer reports in this population compared to the post stroke, probably because of the greater number of variables that are to be considered. Often, one fails to identify the exact cause, type, stage and progression of MND (Wright & Jordan, 1997; Winhammar, Rowe, Henderson & Kiernan, 2005) and the output of studies on swallowing differ with these variables (Higo, Tayama, Watanable & Nitou, 2002). Therefore, these variables are inherent in any research that explores swallowing function in this population. Other variables that affect swallowing physiology in typical and other atypical population are also relevant in this clinical group, complicating research further. Hence, little is known about adaptations of swallow physiology in MND to intrinsic and extrinsic variables.

Thicker consistencies are thought to bring out the sub-clinical symptoms of dysphagia in even the non-bulbar onset MND (Robbins, 1987). A similar difference in spatio-temporal measures was not evident in bulbar onset MND with the measures deviating from typical across all consistency ranges. Comparing the effect of bolus consistency on swallowing physiology of MND, Briani et al. (1998) reported that oro-pharyngeal motility issues were evident in both thin and semi-solid boluses. Similar findings were reported in the study of oro-pharyngeal functions by Clave et al. (2006).In their findings, a group of persons with MND responded atypically to liquid, nectar and pudding consistency boluses. Though differences were noted in specific oro-pharyngeal physiology, the initiation of swallow reflex and bolus transit time was not found to vary with bolus consistency in persons with MND (Fattori, et al., 2006). Ertekin et al. (2000) found that though solid bolus was difficult for triggering the pharyngeal swallow reflex, it was aspirated less frequently by individuals diagnosed with MND. Therefore, this study explained the reason for semi-solid food preference of persons with MND in their routine diet. However, this same consistency was associated with increased esophageal inefficiency compared to liquids in persons with

MND (Fattori et al., 2006).Unlike bolus volume, the risk of aspiration reduced with increasing bolus consistency (Lazarus et al., 1993; Ledder, Novella & Patwa, 2004).

Hadjikoutis, Pickersgill, Dawson and Wiles (2000) investigated the number of swallows per bolus and also the respiratory swallow coordination in thirty two individuals with MND for three bolus volumes- 5ml, 10ml and 20ml. It was found that unlike typical, inspiratory apnea was common in persons with MND and the incidence of this pattern increased with the bolus volume suggesting that increased bolus volume increases the risk of laryngeal penetration/ aspiration in persons with MND. This study also reported multiple swallows per respiratory apnea suggesting that this population tend to swallow during inspiratory apnea, thereby significantly compromising on airway protection during deglutition.

Therefore, the adaptations of swallowing physiology in response to alteration in sensory characteristics of the bolus lack detail. Available studies lack generalizability due to the large number of intrinsic and extrinsic variables associated with the neuro-pathology and swallow.

Instrumentation for Studying the Swallowing Physiology

Over the past decades several methods have been implemented to study the physiology of swallowing in post stroke and MND population. Some of the most commonly used instrumental evaluations include videofluroscopy (Robbins, Hamilton, Lof, &Kempster, 1992; Briani et al., 1998; Han, Paik, & Park, 1999, 2001; Kawai et al., 2003; Chen, Chie, Lin, Chang, Wang & Lien, 2004; Terre & Mearin, 2006;Bian, Choi, Kim, Han & Lee, 2009; Paris et al., 2013), Flexible Endoscopy (Martin, Diamond, Aviv, Sacco, Keen & Blitzer, 1996; Lim et al., 2000; Leder, Novella, & Patwa, 2004; Shirazi, Buchel, Daun, Lenton, & Moussavi, 2012; Pluschinski, Zaretsky, Stöver, Murray, Sader, & Hey, 2016), Scintigraphy (Fattori et al., 2006; Silvia, Fabio & Dantas, 2008; Szacka et al., 2016), Ultrasound (Stone & Shawker, 1986; Kim & Han, 2005),Manometry (Robbins, Hamilton, Lof, & Kempster, 1992; Briani et al, 1998; Hamdy et al, 1997; Higo, Tayama, Watanabe & Nitou, 2002; Kawai et al., 2003), Electromyography (Ertekin, 1998; Mann, Hankey & Cameron, 1999;Umay, Unlu, Saylam, Cakci & Korkmaz, 2013), and combination of one or more of these (Higo, Tayama, Watanabe & Nitou, 2002; Kawai et al., 2003;Solazzo et al., 2014).

Videofluroscopic Swallowing Study (VFSS) has been the most common and also the most reliable source of physiological data. Among the three different methods used by Briani et al. (1998), VFSS was found to give the most reliable findings in a group of individuals diagnosed with MND. This technology is widely employed for detecting silent / non-silent aspiration and also the functional status of oro-pharyngo-laryngo-esophageal structures during swallow (Bleach, 1993; Terre & Mearin, 2006). The findings are also useful in treatment planning in neurogenic dysphagia as proposed by Wright and Jordan (1997). The radiological images obtained through VFSS have been subjected to a variety of analysis procedures for deriving qualitative and quantitative data regarding various swallowing outcome measures.

There are number of analysis methods developed for VFSS study of swallowing so that the procedure gets standardized across practice for comparison and generalization of findings across set-ups. Han, Paik and Park (1999) developed the Functional Dysphagia Scale (FDS) that made an attempt to standardize the VFSS recordings to identify 11 functional measures of swallow in the oral and pharyngeal stages of swallow. This scale was standardized in a group of 103 individuals with post stroke dysphagia and was found to have excellent sensitivity for detecting aspiration. However, the scale did not include many functions that could be evaluated using the VFSS and totally neglected the esophageal function evaluation in post stroke individuals. Therefore, this scale is valid only for assessment of few oro-pharyngeal functions in post stroke population. Han, Paik and Park (2001, 2005) found FDS was 70-80% sensitive in identification of supraglottic penetration and subglottic aspiration in post stroke individuals but it did not predict the long-term prognosis of dysphagia.

There emerged several other scales as an attempt to validate and standardize the VFSS procedure and reporting of findings such as the Modified Barium Swallow Impairment Profile (MBSImP) (Martin-Harris et al, 2008) and the Videofluoroscopic Dysphagia Scale (VDS) (Kim et al, 2012). While MBSImp provides in-depth guideline for physiological parameters and the VDS was developed as tool to predict the long term prognosis of dysphagia with its 14 items that represent 6 oral components and 8 pharyngeal components that are assessed using VFSS. The protocol and analysis method proposed by Martin-Harris et al. (2008) in MBSImp is most widely practiced by clinicians worldwide.

The Modified Barium Swallow Impairment Profile (MBSImp, Martin-Harris et al., 2008) was developed as a means to provide a standardized protocol to perform, interpret and communicate severity of swallowing impairments in persons with dysphagia. The scores for impairment are defined in a consistent and accurate manner so that there is at least 80% agreement in scores across professionals. The measures of validity and reliability of the tool was rigorously tested by the National Institute on Deafness and Other Communication Disorders (NIDCD). The protocol consists of 17 components for assessing the various physiological and functional outcomes of different phases of swallowing. The seventeen components include 6 oral components, 10 pharyngeal components and 1 esophageal componentto provide a comprehensive evaluation of swallowing skill. Many researchers have used the MBSImp to objectively report their VFSS recording in persons with dysphagia (Gullung, Hill, Castell & Martin-Harris, 2012; Belafsky & Kuhn, 2014; Tran, Martin Harris & Pearson, 2016) and are widely accepted to be a tool of high clinical importance.

This review of literature revealed a dearth of studies on physiology of swallow and its adaptations to changes in bolus characteristics in atypical neuro-systems such as stroke and MND. Though primary evidences of difference across bolus characteristics and also across groups are evident, a clinician fails to collect a comprehensive understanding of oro-pharyngo-esophageal physiological functions in these two most frequent diagnostic categories. This gap needs to be filled with adequate information and the findings in literature suggested that the best method of studying physiology is by employing VFSS technology which can be analyzed using protocols such as that of MBSImp. Hence, the present study was planned for its theoretical and clinical relevance.

There exist scarcity of research that have attempted to understand the swallow physiology variations from oral to esophageal stages of swallow in post stroke and MND associated dysphagia. There are also limitations on the studies that have described these physiological variations in deglutition using objective swallow tests with well described protocols. The current research attempted to investigate the swallowing physiology deviations in post stroke and MND associated dysphagia using VFSS based on MBSImp™ protocol and its adaptations to bolus characteristics.

Aim of the study

The aim of the present study was to profile the physiological functions at oral, pharyngeal and esophageal phases of swallow as well as its changes in response to variations in bolus consistency using VideoFluroscopic Swallowing Study in individuals with persistent dysphagia post stroke (Group I) and in individuals diagnosed with Motor Neuron Disease (Group II) analyzed with the standard protocol of Modified Barium Swallow Impairment Profile (MBSImp™).

Objectives of the Study:

The following where the specific objectives of the study:

1. To profile and score the oral, pharyngeal and esophageal components of swallow with Modified Barium Swallow Impairment Profile (MBSImp^{TM} during swallow of five bolus consistencies in group I and group II
2. To compare the oral, pharyngeal and esophageal impairment scores in each consistency across group I and group II.
3. To compare the oral, pharyngeal and esophageal component impairment scores across five bolus consistencies (Thin, Nectar-thick, Honey thick, Pudding and Solid) in Group I and Group II

CHAPTER III

METHOD

This study targeted at detailed analysis of swallow physiology in two neurologically atypical conditions commonly associated with dysphagia- Stroke and Motor Neuron Disease (MND). Videofluroscopy was used to record the movement and functions of oral, pharyngeal and esophageal structures involved in swallowing of boluses of varying consistency and volume. This data was analyzed using a detailed and standardized scoring protocol, Modified Barium Swallow Impairment Profile (MBSImP™). The protocol was employed for identifying the normal and abnormal movements of structures that may contribute to symptoms of dysphagia in these two selected neurological conditions. The study used a standard group comparison design with convenient sampling method for selection of participants. All procedures followed for collection of data was approved by the bio-medical- behavioural ethical committee and was completed under the supervision of qualified medical professionals. Detailed methodology followed for the present study is described in the sections below.

Participants

All participants were selected from the in-patient and out-patient facility of Sree Chithra Tirunal Institute of Medical Sciences and Technology (SCTIMST), Trivandrum. All individuals admitted with stroke in the Stroke Unit or those individuals who reported and were diagnosed with MND in the Neuromedical Ward/ Outpatient clinic of SCTIMST were screened for inclusion criteria.The details are given below. A total of 136 individuals were screened among which 31 individuals satisfying the inclusion criteria were included in the study. The selected participants were divided into 2 groups based on their confirmed medical diagnosis.

Group I: Persons with Dysphagia following Stroke (PsWD-S)

Group II: Persons with Dysphagia following MND (PsWD-MND)

Group I: Persons with Dysphagia following Stroke (PsWD-S)

A total of 102 patients admitted to stroke clinic from the period of December 2016 to April 2017, with a medical diagnosis of Cerebro-Vascular Accident (CVA) were screened for symptoms of swallowing difficulty using the Gugging Swallowing Screen (GUSS) (Trapl et al., 2007). A score of less than 19 indicated swallowing difficulty at the oral, pharyngeal or esophageal stages of swallow. These individuals were shortlisted and were enrolled for follow up on a weekly schedule. GUSS scores were obtained on each visit and the individuals with unresolved dysphagia at 4weeks post stroke were screened for inclusion criteria for the current study. The details are provided below. Few individuals were also included from the follow up sessions of stroke clinic, if they satisfied the below mentioned inclusion criteria. A total of 19 participants (13 Males, 6 Females; mean age: 62.2 years) satisfying all the criteria were enrolled after which a written consent was obtained from the participant/ caregiver. The criteria for inclusion for all participants in this group were as follows:

1. Medical diagnosis of a CVA confirmed by a neurologist with CT/MRI scan.
2. Minimum 4 weeks post stroke.
3. Report of symptoms of swallowing difficulty as in the Clinical Evaluation Protocol for swallowing in Adults (Gayathri & Manjula, 2014).
4. A score of less than 19 in GUSS (Trapl et al., 2007)
5. No report/ history of structural alterations of oral, pharyngeal, laryngeal or esophagealstructures.
6. No history of long term swallowing difficulties prior to onset of the diagnosed neurological condition.
7. No report/ history of allergies to the specific food items used in the study.
8. Ready to provide written consent for participation in the study.

Group II: Persons with Dysphagia following MND (PsWD-MND)

Participants in this group were selected from the outpatient facility of neurology section of SCTIMST, Trivandrum. All individuals diagnosed with a MND were screened for inclusion criteria as mentioned below. A total of 34 individuals were screened and 12 individuals (7 males &7 females, mean age: 51.42 years) who satisfied the criteria enrolled into the study after which a written consent was obtained from the participant/ caregiver.The inclusion criteria followed for this group of participants were as follows:

1. Medical diagnosis of MND confirmed by a neurologist with Electromyoneurography (EMNG) or Electromyography-Nerve conduction studies (EMG-NCS).
2. Report of symptoms of swallowing difficulty as in the Clinical Evaluation Protocol for swallowing in Adults (Gayathri & Manjula, 2014).
3. A score of less than 19 in GUSS (Trapl et al., 2007)
4. No report/ history of structural alterations of oral, pharyngeal, laryngeal or esophageal structures.
5. No history of long term swallowing difficulties prior to onset of the diagnosed neurological condition.
6. No report/ history of allergies to the specific food items used in the study.
7. Ready to provide written consent for participation in the study.

Among the 31 participants enrolled for the current procedure, 4 participants were excluded from the final participation as the complete protocol could not be run on these individuals. The reasons for this exclusion included inability to follow the instructions, inability to maintain posture throughout procedure, cognitive instability and/ or withdrawal of consent from participation in the study. Thus, the total number of participants had to be limited to 27 individuals with 15 participants in CVA group and 12 in the MND group (Table 1).

Table 1

Demographic details and medical history of the final set of participants for the study

Sl.No.	Age/Gender	GUSS Score	Symptoms of swallowing difficulty reported/ Signs noted	Mode of nutrition
Group I: PsWD-S				
1.	72y/F	13/20	Drooling, Delayed cough, Reduced hyolaryngeal excursion	NPO
2.	48y/M	14/20	Immediate cough & throat clearing, multiple swallow attempts, reduced hyolaryngeal, voice change	NPO
3.	67/M	14/20	Drooling, voice change, spontaneous throat clearing, cough, reduced hyo-laryngeal elevation, multiple swallow attempts	NPO
4.	58y/M	16/20	Delayed cough for liquids, reduced hyo-laryngeal elevation	NPO
5.	69y/M	14/20	Delayed cough for liquids and solids, multiple swallow attempts, baseline voice change	NPO
6.	63y/M	14/20	Immediate cough & throat clearing for all food types, multiple swallow attempts	NPO
7.	64y/M	14/20	Occasional drooling, cough for liquids, delayed initiation of swallow, reduced laryngeal elevation	NPO
8.	70y/F	16/20	Delayed cough, reduced laryngeal elevation, delayed swallow initiation	NPO
9.	62y/M	15/20	Immediate cough/ throat clearing, occasional	NPO

			drooling, voice change, delayed swallow initiation	
10.	70y/M	14/20	Immediate cough/ throat clearing, occasional drooling, voice change, delayed swallow initiation	NPO
11.	50y/M	14/20	Cough/throat clearing for liquids, multiple swallow attempts, reduced laryngeal elevation	NPO
12.	58y/F	16/20	Throat clearing for liquids, multiple swallow attempts, reduced hyo laryngeal excursion	NPO
13.	62y/M	13/20	Delayed swallow initiation, Cough for liquids, multiple swallow attempts, drooling for liquids	NPO
14.	71y/M	15/20	Delayed swallow initiation, Baseline voice change	NPO
15.	49y/M	17/20	Voice change/ throat clearing for liquids	NPO
Group II: PsWD-MND				
16.	60y/M	14/20	Delayed cough, reduced tongue movements, difficulty with liquids	Oral
17.	58y/M	17/20	Immediate cough following liquid intake, prolonged meal time	Oral
18.	67y/F	14/20	Difficulty with liquid intake, prolonged duration, reduced laryngeal excursion	Oral
19.	53y/F	10/20	difficulty forming bolus, multiple swallow attempts, prolonged meal time	Oral
20.	45y/F	17/20	Occasional cough during intake of liquids,	Oral

			multiple swallows	
21.	38y/F	9/20	Immediate cough, breathlessness, delayed initiation of swallowdrooling, difficulty forming bolus, prolonged swallow time, multiple swallow attempts, reduced hyo-laryngeal excursion	Oral
22.	54y/F	16/20	Immediate cough & throat clearing, globus sensation, multiple swallows, prolonged duration for swallow	Oral
23.	49y/M	18/20	Occasional cough/ throat clearing, difficulty forming bolus	Oral
24.	61y/M	18/20	Occasional cough and drooling, prolonged swallow time	Oral
25.	54y/M	17/20	Cough for fluid intake, multiple swallow attempts	Oral
26.	36y/F	10/20	Immediate cough, Prolonged oral phase, Difficulty in swallow initiation, Drooling	Oral
27.	42y/M	11/20	Difficulty forming bolus, drooling, cough for liquids, multiple swallow attempts	Oral

Note: GUSS: Gugging Swallowing Score; PsWD-S: Persons with Dysphagia following Stroke; PsWD-MND: Persons with Dysphagia following Motor Neuron Disease; NPO: Nil Per Os/ Nothing through the mouth

Testing Environment:

All videofluroscopic Swallowing Study (VFSS) were recorded in the Radiology Cath Lab at SCTIMST, Trivandrum. Recordings were carried out in a single room setting in the presence of the investigators (SLP and Radiology technician) after considering the recommended radioactive insulation using X-ray lead aprons, thyroid collars, masks and gloves. The participants were seated in an upright posture on a non reclinable chair with armrest, positioned between the C-arm imager. Height and position adjustments were altered accordingly for lateral and anterior-posterior recordings such that oro-pharyngo-esophageal system was clearly visible in the final VFSS recording. For the anterior-posterior recording, the position of the chair was altered by the investigator and the participant was then made to sit in the upright position.

Materials used:

The procedure used for VFSS demanded the following materials to be used for data collection.

1. Barium: Microbar Suspension (Barium Sulphate Oral Suspension), Microbar barium sulphate powder
2. Food materials used: Water, Rice Starch, Dabur Honey, Crushed Britannia Good Day biscuits mixed with water to give a pudding consistency and Britannia Tiger Biscuit
3. Utensils used: Mixing bowl, Tea-spoon Table-spoon, Cup, 5ml syringe
4. Cleaning/ Anti infectants used: MicroshieldHandrub, Microshield Handwash
5. Personal hygiene materials: X-ray lead apron, X-ray thyroid collar, Surgical mask, Surgical cap, Gloves
6. Patient hygiene: Hospital gowns

Tools used:

Gugging Swallowing Screen (Trapl et al., 2007): This is a subjective rating scale for swallowing performance that is used to screen individuals at risk for swallowing difficulties.

It consists of two parts- indirect and direct swallowing test. The indirect swallowing tests assess for vigilance, voluntary cough/ throat clearing and saliva swallow. The direct swallowing test use both fluids and non-fluids for deriving scores based on various parameters such as deglutition, involuntary cough, drooling and voice change during swallow of semi-solid, liquid and solid boluses.The test is scored on a scale of 0 to 20 where 0 indicates severe swallowing difficulty and 20 indicates near normal performance. GUSS is considered as a potentially better alternative to other dysphagia screens due to its safer progression of oral intake, more thorough evaluation of swallowing, and ability to enable earlier nutrition (John & Berger, 2015).

Video-fluroscopic Imaging System (GE Innova 3131 Biplane): Videofluroscopic assessment of swallowing was carried out using the GE Innova 3131 Biplane in the Digital Subtraction Angiography (DSA) lab of the SCTIMST Hospital. The recording time was set based on the task with a sampling frame of 7.5 frames/ second and a recording resolution of 512x512. Radiation strength of the fluoroscopic system was controlled by Automatic Exposure Control (AEC) X-ray system which automatically terminated the radiation when it is beyond the predetermined level. All the recording procedures were carried out by a radiology technician under the supervision of a qualified radiologist.

Instruction given:

Instructions were given in a language known and understood by the participant. If the investigator was not proficient in the language used by the participant, Instructions were translated by the caregiver and told to the participant. Comprehension of the instruction was confirmed with gestures and the same was repeated before introduction of each bolus. The content of the instruction was as follows:

1. Thin Liquids

Teaspoon administration: "Hold this in your mouth until I ask you to swallow."

Single cup sip: "Take a sip normally and hold it in your mouth until I ask you to swallow".

Sequential Swallow: "Drink this in the usual manner until I ask you to stop."

2. Nectar thick liquid:

Teaspoon administration: "Hold this in your mouth until I ask you to swallow."

Single cup sip: "Take a sip normally and hold it in your mouth until I ask you to swallow".

Sequential Swallow: "Drink this in the usual manner until I ask you to stop."

3. Honey thick liquid:

Teaspoon administration: "Hold this in your mouth until I ask you to swallow."

4. Pudding consistency:

Teaspoon administration: "Swallow this when you are ready."

5. Solid:

"Chew this as you normally would and then swallow when you are ready."

Procedure:

Individuals satisfying the inclusion criteria were referred for VFSS after obtaining a verbal consent. The participants were enrolled on appointment basis in consultation with the radiology department, SCTIMST. The procedure followed for VFSS recordings for this study can be described in the following phases:

1. Pre-recording Phase:

Enroll for VFSS: The participants were instructed to ensure an interval of 2 hours between their meal time and the data recording session. All participants were screened for any contraindication for VFSS procedure such as implanted devices (Cochlear implant/ brainstem implant/ pace maker) or allergy to any particular food material before enrollment.

Obtaining written consent: The investigator summarized the purpose and procedure for VFSS. The participant/ caregiver signed a written consent to enroll and participate in the research study.

Preparation of bolus: Five bolus consistencies were used for the study- thin liquid, nectar thick, honey thick, pudding consistency and solid. For thin liquid consistency, water was used. Details regarding bolus and bolus consistencies that were used for VFSS recording for the current study are summarized in Table 2.

Participant preparation: The participant and the investigator wore the sterilized hospitals gowns. The investigators and radiology professionals present in therecording room insulated themselves with the recommended measures using x-ray lead aprons, thyroid collar, masks, gloves and cap. The participants were instructed to

Table 2

Details of bolus preparation and volumes presented

Consistency	Material used	Recipe for bolus preparation	Volumes presented	Presentation mode
Liquid	Water, Barium Sulphate Oral Suspension	30ml barium sulphate oral suspension mixed with 250 ml water	5ml, Self-directed intake	1. Teaspoon 2. Cup sip

Nectar	Rice Starch, Barium Sulphate Oral Suspension	30ml barium sulphate oral suspension mixed with 250 ml starch	5ml, Self-directed intake	1. Teaspoon 2. Cup sip
Honey	Dabur Honey, Barium Sulphate Oral Suspension	10ml barium sulphate oral suspension mixed with 100 ml honey	5ml	Teaspoon
Pudding	Good Day Biscuits, Barium sulphate powder	100 grams of crushed biscuits and 10grams of barium sulphate powder mixed with warm water to give pudding consistency	5ml	Tea spoon
Solid	Biscuits, Barium sulphate powder	Biscuit coated with a paste prepared by mixing Barium sulphate powder and warm water	½ biscuit, Self-directed intake	By hand

maintain an upright posture throughout the procedure. In case of difficulty in maintaining the posture, seat belts were used to avoid body movements during the recording session. After ensuring comfortable seating of the participant, the procedure of study was detailed to the participants. They were informed about the various boluses that would be provided to them and were also instructed to swallow only on investigator's instruction. The investigator also briefed regarding the possible side effects of the contrast agent.

2. Recording Protocol:

   The standard MBSImP^{TM} Protocol proposed by Martin-Harris (2008) was followed for radiographic recording of the swallow function (Table 3). All individuals completed the protocol in the same sequence, one bolus after the other. The participant was given specific instructions for each swallow before presenting the specific bolus. Comprehension of the instruction was ensured with gestural or verbal response. On indication by the radiologist, the prepared bolus was presented by the SLP to the participant for swallow. A single episode of radiation lasted for approximately 8-10 seconds for liquids and 15-20 seconds for solid bolus. Movement of the bolus was traced from the lips till the lower esophageal sphincter.All recordings in the lateral view were completed before shifting the orientation to anterior-posterior view. A total of 12 swallows were obtained per participant. All boluses, its presentation, order and instructions used in this study was exactly as proposed by Martin-Harris (2008) in the MBSImP^{TM} protocol.

3. Post recording Protocol:

   After obtaining the VFSS recording for the complete protocol, the participants were released from the VFSS seat and transferred to ward/ OPD as indicated in their case sheet. The VFSS recordings were digitized and written on to a hard disk by the radiologist in '.avi' format. The same was used for scoring and offline analysis using MBSImp^{TM} protocol, at a later point of time. A quick report of the study was provided to the consultant for further assessment, diagnosis or management without any significant delay.

Table 3.

The MBSImp™ Protocol used for VFSS recordings

Swallow number	Type of bolus	Bolus volume	Mode of presentation	Type of swallow
Lateral View				
1.	Thin liquid (Water)	5 ml	Tea spoon	Single
2.	Thin liquid (Water)	5 ml	Tea spoon	Single
3.	Thin liquid (Water)	Patient determined	Cup	Single
4.	Thin liquid (Water)	Patient determined	Cup	Sequential
5.	Nectar thick Liquid (Rice Starch)	5 ml	Tea spoon	Single
6.	Nectar thick Liquid (Rice Starch)	Patient determined	Cup	Single
7.	Nectar thick Liquid (Rice Starch)	Patient determined	Cup	Sequential
8.	Honey thick Liquid (Honey)	5 ml	Tea spoon	Single
9.	Pudding consistency (Biscuit pudding)	5 ml	Tea spoon	Single
10.	Solid (Biscuit)	½	Plate	Patient determined
Anterior- Posterior View				
11.	Nectar thick Liquid (Rice	5 ml	Tea spoon	Single

	Starch)			
12.	Pudding consistency (Biscuit pudding)	5 ml	Tea spoon	Single

Analyses

1. *Establishing MBSImP™Scores:* A total of 12 swallows were obtained from each participant as per the bolus presentation protocol (Martin-Harris et al., 2008). Each of these swallows were scored on the 17 components of swallow which includes 6 components in oral stage, 10 in pharyngeal stage and 1 in esophageal stage (See Appendix). The worst performance score (Overall Impairment Score) in a bolus consistency was tabulated for all participants across the 17 components of swallow. This data formed the raw data for further analysis.

2. Test re-test Reliability: A random 10% of the data (2 recordings) was re-scored by the investigator for establishing test-re-test reliability. The re-scoring was done after 4 weeks of initial scoring to avoid any possible investigator bias. An agreement was obtained in 80% of the MBSImp™ components, indicating good test-re test reliability.

3. Inter-judge reliability: A random 10% of data (2 recordings) was scored independently by another Speech Language Pathologist trained in MBSImP™ Any discrepancy of more than 20% was discussed and subjected to independent re-analysis. The procedure continued till a consensus was reached in the scoring of VFSS recordings for atleast 80% of the MBSImp™ components.

4. Statistical Comparisons: The data was subjected to detailed statistical analysis using Social Sciences Software package (SPSS) (Version 21) to answer the objectives of the study. The following statistical comparisons were made:

- Descriptive statistics to compute the mean impairments scores at the oral, pharyngeal and esophageal stages

- Tests of normality (Shapiro Wilk'stest)to study the data distribution.
- Non Parametric comparisons (Friedman's Test and Wilcoxon's test) to compare the impairments scores for different bolus consistencies within Group I and Group II
- Non Parametric comparisons (Mann Whitney U test) to compare the impairment scores at oral, pharyngeal and esophageal stages across Group I and Group II
- Non Parametric comparisons (Wilcoxon Signed Rank) test to compare the impairments at the oral, pharyngeal and esophageal levels

CHAPTER IV

RESULTS AND DISCUSSION

The data obtained after analysis of VFSS recordings using the MBSImp^{TM} protocol provided scores for the 17 components of oral, pharyngeal and esophageal swallow, as addressed in the said protocol. This was tabulated for each participant for each of the 12 swallows recorded across bolus consistency. Overall, this analysis yielded 204 data points for each participant. Overall Impairment (OI) score for each consistency was obtained from this data set and was defined as 'the maximum impairment score recorded during swallow of each bolus consistency'. The OI score data was then subjected to detailed statistical analysis for meeting the objectives of this study.

1. Score and profile the oral, pharyngeal and esophageal components of swallow with Modified Barium Swallow Impairment Profile (MBSImp^{TM}) during swallow of five bolus consistencies in group I and group II
2. Compare the oral, pharyngeal and esophageal impairment scores in each consistency across group I and group II.
3. Compare the oral, pharyngeal and esophageal component impairment scores across five bolus consistencies (Thin, Nectar-thick, Honey thick, Pudding and Solid) in Group I and Group II

The data was run with Shapiro-Wilk's test of normality for studying the distribution of data points. The results showed that in Group I, normality criterion wassatisfied for few components in honey-thick (PR[1]: $W=0.81$, $p < 0.05$) and solid (BP[2]: $W=0.88$, $p < 0.05$) consistencies. More components satisfied the criterion in group 2 with normality of component score data in thin (IPS[3]: $W= 0.86$, $p<0.05$; TBR[4]: $W=0.88$, $p < 0.05$), nectar-thick

[1] PR= Pharyngeal Residue
[2] BP= Bolus preparation
[3] IPS= Initiation of Pharyngeal swallow
[4] TBR=Tongue Base Retraction

(OR[5]: W=0.87, $p < 0.05$; IPS[6]: W=0.91, $p < 0.05$), honey-thick (PR[7]: W=0.88, $p < 0.05$), pudding (BT[8]: W=0.87, $p < 0.05$; OR; W=0.86, $p < 0.05$; EC[9]: W=0.86, $p < 0.05$) and solid (BP[10]: W=0.87, $p < 0.05$;BT: W=0.87, $p < 0.05$) consistencies. Hence, further comparisons within and across groups were made using nonparametric comparisons. The results of statistical analysis of the data are detailed and the results are discussed under the following sections:

1. Impairment scores across bolus consistenciesin group I and group II
2. Comparison of MBSImp™ component scores across group I and group II in each bolus consistency.
3. Comparison of MBSImp™ component scores across bolus consistency in group I and group II.

Impairment Scores Across Bolus Consistencies in Group I and Group II

The raw data was treated with frequency analysis for each component score in group I and Group II. Table 4 and Table 5 provide the percentage of participants in each group who obtained a specific component score as per the MBSImp™ scoring protocol. This analysis was expected to identify the most common physiological impairment in group I and group II and also indicate the variation in physiological impairment scores across the spectrum of bolus consistencies used in this study.

[5] OR= Oral Residue
[6] IPS= Initiation of Pharyngeal Swallow
[7] PR= Pharyngeal Residue
[8] BT= Bolus transport
[9] EC=Esophageal Clearance
[10] BP=Bolus preparation

Table 4

Percentage of group I participants with each component scores in each bolus consistency

		Bolus Consistency				
Components	**Scores**	**Water**	**Nectar**	**Honey**	**Pudding**	**Solid**
LC	0	33.3	**46.7**	**60.0**	**60.0**	**80.0**
	1	**40.0**	26.7	33.3	26.7	20.0
	2	20.0	20.0	0.00	13.3	0.00
	3	6.7	6.7	6.7	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
TC	0	33.3	20.0	**33.3**	-	-
	1	**40.0**	**46.7**	**33.3**	-	-
	2	26.7	33.3	**33.3**	-	-
	3	0.00	0.00	0.00	-	-
BP	0	-	-	-	-	13.3
	1	-	-	-	-	**40.0**
	2	-	-	-	-	**40.0**
	3	-	-	-	-	6.7
BT	0	**46.7**	**46.7**	**53.3**	**33.3**	**33.3**
	1	26.7	20.0	20.0	26.7	**33.3**
	2	13.3	26.7	20.0	13.3	**33.3**
	3	13.3	6.7	6.7	26.7	0.00
	4	0.00	0.00	0.00	0.00	0.00
OR	0	6.7	6.7	6.7	0.00	0.00
	1	**53.3**	**60.0**	33.3	33.3	26.7
	2	26.7	20.0	**53.3**	**53.3**	**53.3**
	3	13.3	13.3	6.7	6.7	13.3
	4	0.00	0.00	0.00	6.7	6.7
IPS	0	20.0	6.7	0.00	0.00	0.00
	1	20.0	26.7	33.3	**40.0**	**46.7**
	2	20.0	**40.0**	**46.7**	33.3	40.0
	3	**40.0**	26.7	20.0	26.7	13.3
	4	0.00	0.00	0.00	0.00	0.00
SPE	0	**80.0**	**86.7**	**86.7**	**86.7**	**86.7**
	1	20.0	6.7	6..7	13.3	13.3
	2	0.00	6.7	6.7	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
LE	0	40.0	46.7	**60.0**	**66.7**	**66.7**
	1	**60.0**	**53.3**	40.0	33.3	33.3
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
AHE	0	**53.3**	46.7	**53.3**	**60.0**	**60.0**
	1	40.0	**53.3**	46.7	40.0	40.0
	2	6.7	0.00	0.00	0.00	0.00
EM	0	40.0	40.0	33.3	40.0	33.3
	1	**60.0**	**60.0**	**60.00**	**46.7**	**53.3**
	2	0.00	0.00	6.70	13.3	13.3
LVC	0	20.0	13.3	6.7	6.7	6.7

	1	**80.0**	**86.7**	**93.3**	**80.0**	**80.0**
	2	0.00	0.00	0.00	13.3	13.3
PSW	0	33.3	33.3	20.0	20.0	13.3
	1	**66.7**	**66.7**	**80.0**	**80.0**	**86.7**
	2	0.00	0.00	0.00	0.00	0.00
PC	0	-	26.7	-	6.7	-
	1	-	**73.3**	**-**	**86.7**	-
	2	-	0.00	-	6.7	-
	3	-	0.00	-	0.00	-
PESO	0	33.3	26.7	26.7	6.7	6.7
	1	**46.7**	**46.7**	**40.0**	**46.7**	**53.3**
	2	20.0	20.0	33.3	**46.7**	40.0
	3		6.7	0.00	0.00	0.00
TBR	0	20.0	6.7	6.7	40.0	0.00
	1	26.7	40.0	**53.3**	**46.7**	40.0
	2	**46.7**	**46.7**	33.3	13.3	**53.3**
	3	6.7	6.7	6.7	0.00	6.7
	4	0.00	0.00	0.00	0.00	0.00
PR	0	13.3	6.7	13.3	20.0	33.3
	1	**46.7**	**46.7**	26.7	**60.0**	**46.7**
	2	33.3	**46.7**	**40.0**	20.0	20.0
	3	6.7	0.00	20.0	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
EC	0	-	**60.0**	**-**	**66.7**	-
	1	-	33.3	-	26.7	-
	2	-	6.7	-	6.7	-
	3	-	0.00	-	0.00	-
	4	-	0.00	-	0.00	-

(*Note:*1. **Bold** indicates the highest percentage in each component score in each bolus consistency; 2. '- ' indicates that the component was not calculated for the particular consistency, as per MBSImp^{TM} guidelines; 3. LC: Lip Closure; TC: Tongue Control during bolus hold; BP: Bolus Preparation; BT: Bolus Transport; OR: Oral Residue; IPS: Initiation of Pharyngeal Swallow; SPE: Soft Palate Elevation; LE: Laryngeal Elevation; AHE: Anterior Hyoid Excursion; EM: Epiglottic Movement; LVM: Laryngeal Vestibular Closure; PSW: Pharyngeal Stripping Wave; PC: Pharyngeal Contraction; PESO: Pharyngo Esophageal Segment Opening; TBR: Tongue Base Retraction; PR: Pharyngeal Residue; EC: Esophageal Clearance)

For better comprehension, the data is represented in Figure 1. From the Figure, mild oral deficits were evident in majority of participants in group I, specifically with component LC and TC that scored a component score of '1'. This indicated inter-labial fluid leakage but not till anterior lips and impaired bolus hold prior to swallow that makes the fluid fall into the lateral sulci or floor of the mouth before the swallow is initiated. Majority of participants had a score of ‘0’ for the tongue movement for bolus transport (BT) that indicated quick and brisk lingual movement for swallow of liquids. Attributable to impaired scores of LC and BT, nearly half the population had mild impairment in the functional efficiency of oral stage (OR) scoring ‘1’ that suggested that trace residue of bolus remained in the oral cavity post swallow.

At least 80% of the population had impaired initiation of pharyngeal reflex (IPS) with majority of them initiating the swallow when the bolus head reached the pyriform sinus (score 3). This may be related to impaired tongue control leading to posterior spillage or due to a delay in initiation of pharyngeal reflex that may be further related to impaired sensory-motor integration of bolus information onto the swallow sequence. Majority of participants had preserved soft palate function (SPE score ‘0’). Other airway protection functions (LE,EM, LVC) were impaired partially with these functions scoring ‘1’ which indicated incomplete functioning. Interestingly, AHE was within normal functional level (score 0). Other pharyngeal functions such as the pharyngeal stripping wave (PSW) and the UES opening (PESO) were also impaired partially (Score 1) with incomplete functioning of these structures. This may be related to impaired triggering of swallowing sequences by reduced tongue base retraction (TBR, Score 2) as indicated by a narrow gap between tongue base and the posterior pharyngeal wall. Overall, the pharyngeal phase efficiency was mildly impaired with component PR scoring ‘1’ that indicated trace residue in the pharyngeal structures post swallow of thin liquids.

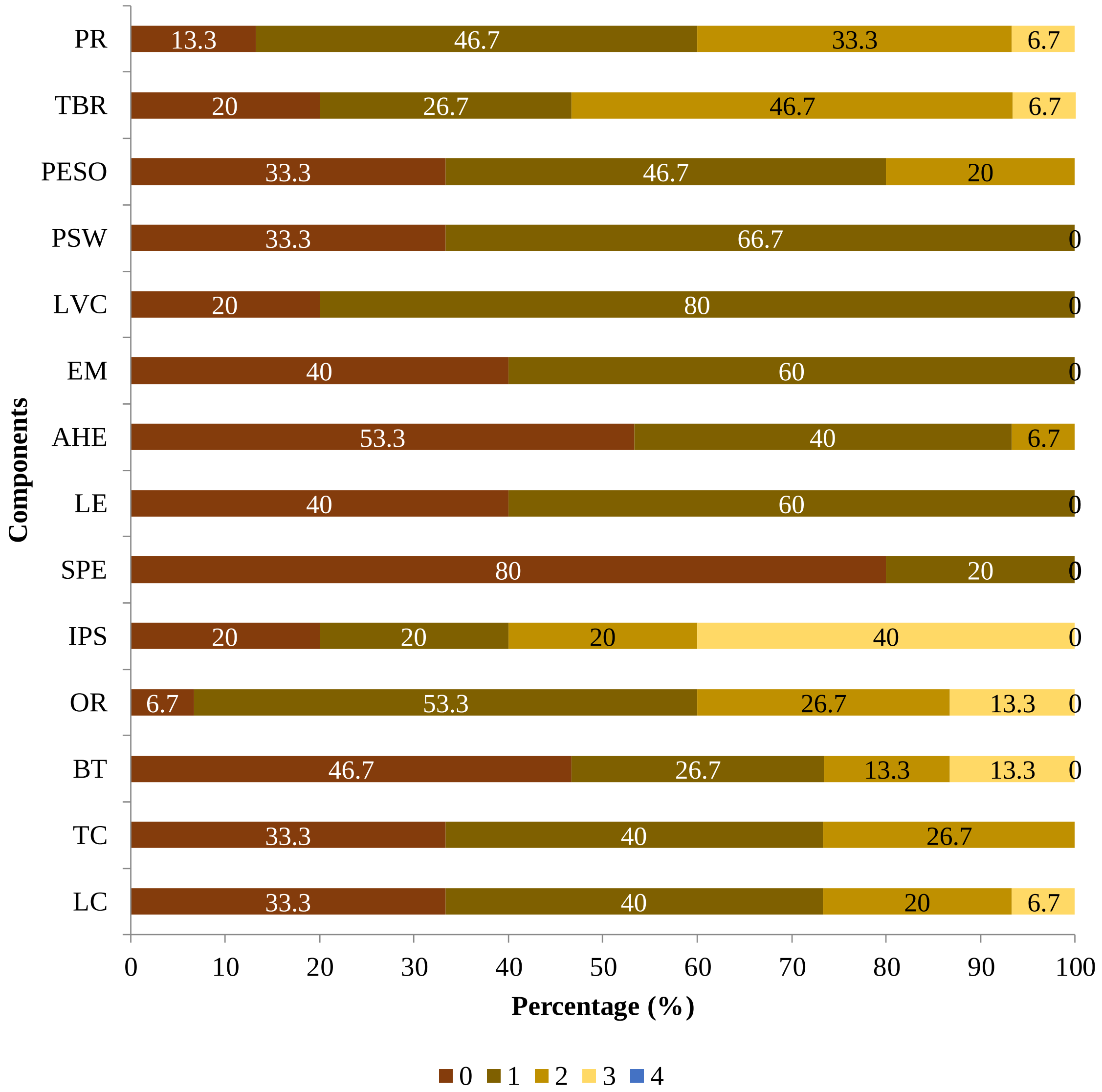

Figure1.Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of thin liquid (Water) for Group 1.

Similar interpretations could be made from figure 2 for swallow of nectar-thick and honey-thick liquids. Many components performed similar to swallow of thin liquids and only the differences in performance are detailed here. In the oral stage, unlike the swallow of liquids, thicker liquids did not have interlabial leakage and the lip closure was within functional levels in majority of participants (Score 0). Therefore, the impaired oral efficiency for swallow of nectar thick fluids (OR, Score 1) could be attributed to the reduced tongue control for bolus hold (TC, score 1).Swallow reflex was triggered at a higher point in the pharyngeal cavity (Score ‘2’)

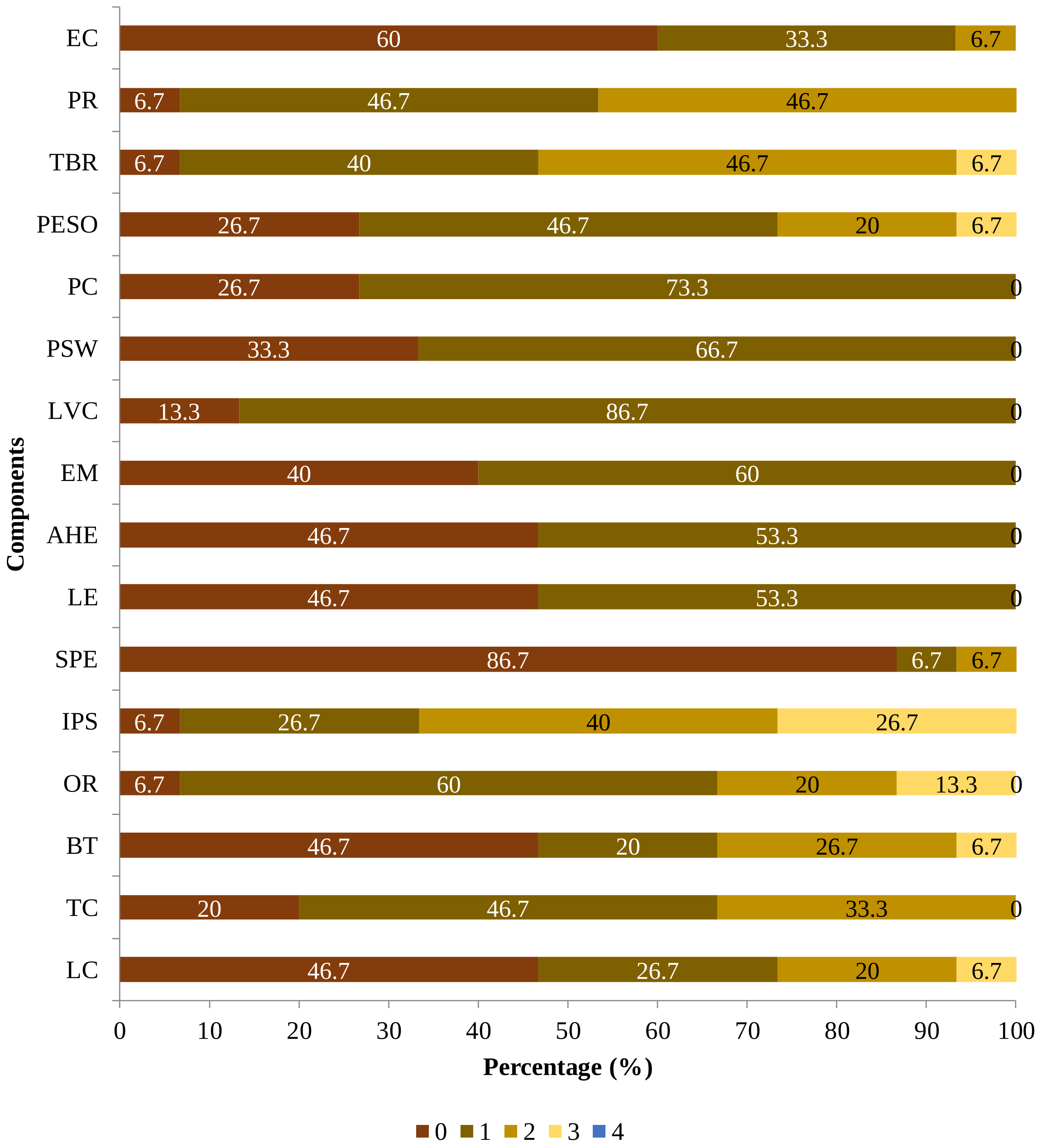

Figure 2. Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of nectar-thick liquid (Rice Starch) for Group I.

when the bolus head reached the laryngeal surface of epiglottis. This may be because of the increased sensory input by the thicker consistency of passing bolus and the longer time available for integration. Difference in performance was also noticed in the AHE that was within normal limits for swallow of thin liquids but was partially impaired for swallow of nectar thick liquid (Score 1). In this consistency, additional inferences regarding pharyngeal contraction could be made with majority of participants having incomplete pharyngeal contraction that resulted in pharyngeal residue at various locations in the pharyngeal cavity. Pharyngeal efficiency was more impaired in thicker liquid consistency with majority of population scoring '1' or '2' indicating trace or collection of residue in the pharyngeal structures. Other pharyngeal components scored similar to thin liquids. Esophageal function (EC) was within functional limits (Score 0) for nectar-thick liquids.

The next higher consistency included in the protocol, honey-thick liquids, passed though the swallowing system with similar performance outputs as the nectar-thick with few differences in specific oral and pharyngeal components as seen in figure 3. In the oral phase, equal percentage of population scored component scores of 0 to 2 in TC suggesting that the performance of tongue control for bolus head was variable across participants. Thicker consistency bolus is more cohesive and can easily be held as a bolus for swallow reducing the chances of posterior spillage. Distribution of scores suggests the variability of involvement of tongue in this function. This may be a major contributor in the reduced efficiency of oral stage of swallow as is evident from the decreased score of OR (Score 2) that indicated collection of residue in the oral structures after swallow. In the pharyngeal phase, the airway protective physiology performed as a combination of the previous two consistencies. While LE and AHE were functionally adequate in majority of participants (Score 0), EM and LVC

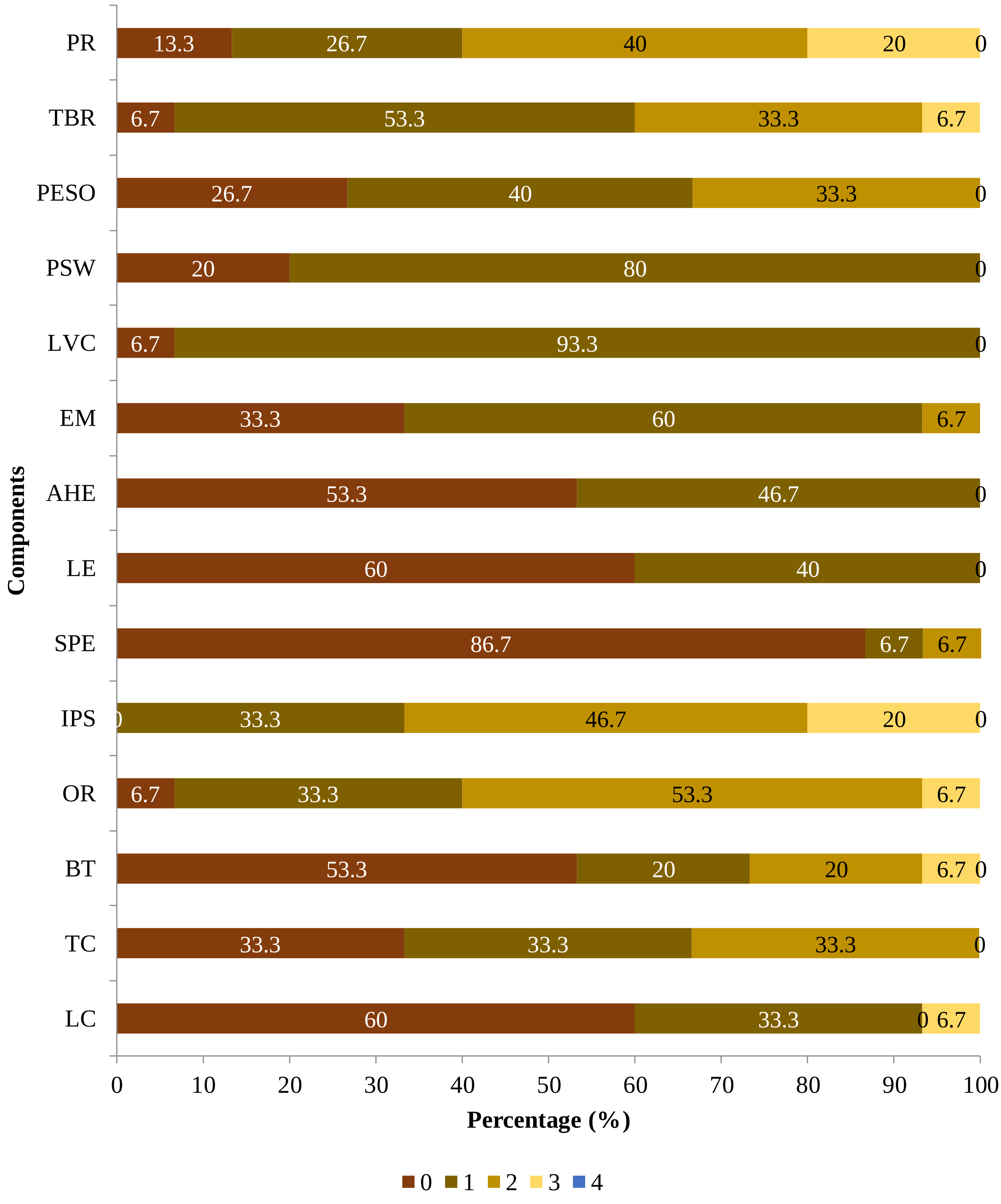

Figure 3. Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of honey -thick liquid (Honey) for Group I.

were only partially functional with incomplete function (Score 1). Tongue base retracted better with this consistency that only a trace gap was evident during swallow. There was collection of residue in the pharyngeal structures in majority of the population in group I (score 2).

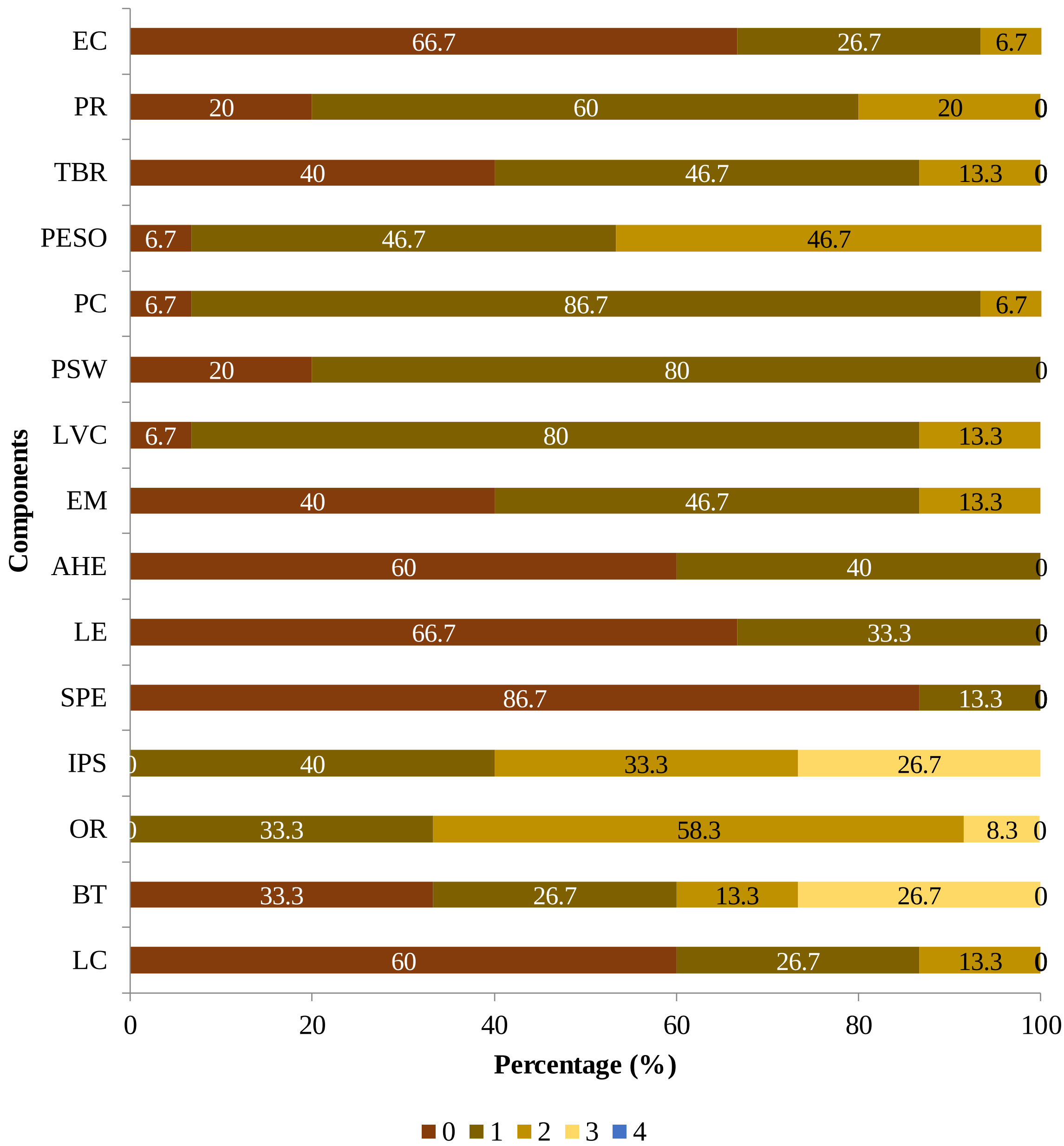

*Figure4.*Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of pudding -thick solid (Soaked Biscuit) for Group I.

From figure 4, component scores during swallow of semi-solid (pudding consistency) could be inferred. In spite of functional LC and BT components, the oral stage was left with residue collection in its structures (OR Score 2). Compared to the thinner consistencies, the variations in the score of BT was higher with only 33.3% of population scoring a functional score. This indicated that more number of participants had difficulty of varying degree to transport the thicker bolus through the oral cavity for swallow, probably contributing to the higher OR score. Pharyngeal swallow could be initiated at a higher locus (Valleculae) in pharynx with majority of population scoring 1 in the component IPS. Other pharyngeal components performed similar to the honey-thick consistency except PESO that obstructed the bolus flow to a greater extent.

The process of mastication was an additional component assessed with the solid consistency and the scores of majority of the population (Score 1, 2) suggests that at least 80% of them had slow, prolonged chewing with chunks of solids left un-chewed in the mouth. Unbroken solid and its mass on the tongue may be a contributing factor in the increased severity in impairment scores of lingual propulsion of bolus through the oral cavity (BT, score 1,2). Together these inefficiencies lead to severe inefficiency in the oral stage with food residue. This consistency caused severe impairment in OR atleast in 6.7% of the population, unlike the thinner consistencies included in the protocol. All other pharyngeal components performed similar to pudding consistency except the TBR that showed wider gap between the base of the tongue and posterior pharyngeal wall (Score 2). This may be related to the difficulty in holding un-chewed food in the anterior oral cavity while the mashed foods are transported into the pharynx. This simultaneous incongruous function might cause a functional inefficiency in lingual motion during the oro-pharyngeal phases of swallow.

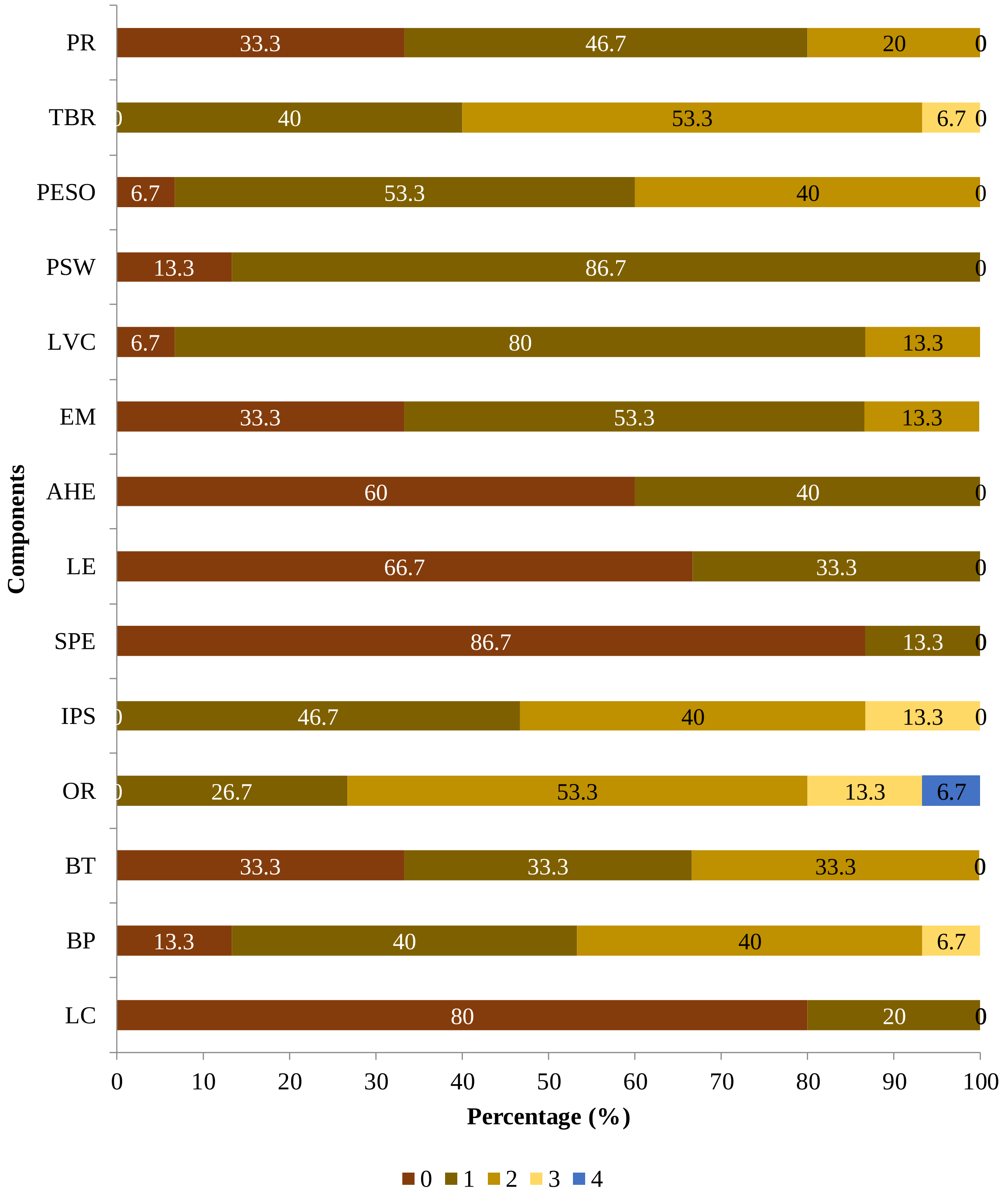

*Figure5.*Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of solid bolus (Biscuit) for Group I.

Gathering observations from the above detailed data (Table 4& Figure 1-5), SPE was the only physiology that remained intact irrespective of the bolus consistency in majority of the participants in Group I. Certain physiological components such as LC, IPS and LE had higher scores in Water and the scores lowered with increasing bolus consistency. Other components such as the EM, LVC, PSW, PC, PESO and EC were independent of the bolus consistency variable. The scores of OR increased with bolus consistency and inconsistent variability in scores could be observed in TC, BT, TBR, AHE and PR. The component score of IPS was the highest among majority of participants in Group I. The esophageal component scores were within the normal function range for all participants in Group I.

Table 5 summarizes the percentage of participants in the Group II who obtained a specific component score as per the MBSImp™scoring protocol.

Table 5

Percentage of Group II participants with each component scores across bolus consistencies

		Bolus Consistency				
Components	**Scores**	**Water**	**Nectar**	**Honey**	**Pudding**	**Solid**
LC	0	**66.7**	**58.3**	**58.3**	**66.7**	**58.3**
	1	8.3	16.7	25.0	16.7	33.3
	2	16.7	8.3	16.7	16.7	8.3
	3	8.3	16.7	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
TC	0	**33.3**	**41.7**	33.3	-	-
	1	16.7	16.7	16.7	-	-
	2	16.7	33.3	**50.0**	-	-
	3	**33.3**	8.3	0.00-	-	-
BP	0	-	-	-	-	**33.3**
	1	-	-	-	-	25.0
	2	-	-	-	-	**33.3**
	3	-	-	-	-	8.3
BT	0	**58.3**	**41.7**	**50.0**	25.0	25.0
	1	25.0	**41.7**	33.3	**33.3**	**33.3**
	2	8.3	8.3	8.3	**33.3**	**33.3**
	3	8.3	8.3	8.3	0.00	0.00
	4	0.00	0.00	0.00	8.3	8.3
OR	0	25.0	25.0	8.3	0.00	0.00
	1	16.7	25.0	**50.0**	33.3	**50.0**
	2	**50.0**	**41.7**	25.0	**41.7**	33.3
	3	0.00	0.00	8.3	16.7	8.3
	4	8.3	8.3	8.3	8.3	8.3
IPS	0	25.0	25.0	16.7	0.00	0.00

	1	16.7	16.7	33.3	33.3	**66.7**
	2	**41.7**	**33.3**	**41.7**	**50.0**	16.7
	3	16.7	16.7	0.00	16.7	8.3
	4	0.00	8.3	8.3	0.00	8.3
SPE	0	**91.7**	**91.7**	**91.7**	**91.7**	**91.7**
	1	8.3	0.00	8.3	8.3	8.3
	2	0.00	8.3	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	41.7
LE	0	**58.3**	**58.3**	**58.3**	33.3	**50.0**
	1	25.0	25.0	41.7	**58.3**	33.3
	2	16.7	16.7	0.00	8.3	8.3
	3	0.00	0.00	0.00	0.00	8.3
AHE	0	**50.0**	41.7	33.3	33.3	41.7
	1	41.7	**50.0**	**58.3**	**58.3**	**50.0**
	2	8.3	8.3	8.3	8.3	8.3
EM	0	41.7	41.7	33.3	33.3	25.0
	1	**58.3**	**58.3**	**66.7**	**66.7**	**75.0**
	2	0.00	0.00	0.00	0.00	0.00
LVC	0	**41.7**	**50.0**	33.3	25.0	25.0
	1	**41.7**	41.7	**66.7**	**75.0**	**75.0**
	2	16.7	8.3	0.00	0.00	0.00
PSW	0	**58.3**	**58.3**	33.3	16.7	16.7
	1	25.0	33.3	**58.3**	**75.0**	**75.0**
	2	16.7	8.3	8.3	8.3	8.3
PC	0	-	33.3	-	25.0	-
	1	-	**58.3**	**-**	**66.7**	-
	2	-	8.3	-	8.3	-
	3	-	0.00	-	0.00	-
PESO	0	**58.3**	**58.3**	**41.7**	8.3	8.3
	1	8.3	16.7	33.3	**66.7**	**66.7**
	2	33.3	25.0	16.7	16.7	16.7
	3	0.00	0.00	8.3	8.3	8.3
TBR	0	**33.3**	33.3	8.3	25.0	33.3
	1	16.7	16.7	**41.7**	**66.7**	**58.3**
	2	**33.3**	**41.7**	**41.7**	8.3	8.3
	3	8.3	8.3	8.3	0.00	0.00
	4	8.3	0.00	0.00	0.00	0.00
PR	0	33.3	**33.3**	16.7	16.7	0.00
	1	**41.7**	**33.3**	**50.0**	**50.0**	**66.7**
	2	8.3	25.0	25.0	25.0	16.7
	3	16.7	0.00	8.3	0.00	8.3
	4	0.00	8.3	0.00	8.3	8.3
EC	0	-	**41.7**	-	33.3	-
	1	-	33.3	**-**	**41.7**	-
	2	-	25.0	-	16.7	-
	3	-	0.00	-	8.3	-
	4	-	0.00	-	0.00	-

(*Note:* 1. **Bold** indicates the highest percentage in each component score in each bolus consistency; 2. LC: Lip Closure; TC: Tongue Control during bolus hold; BP: Bolus Preparation; BT: Bolus Transport; OR: Oral

Residue; IPS: Initiation of Pharyngeal Swallow; SPE: Soft Palate Elevation; LE: Laryngeal Elevation; AHE: Anterior Hyoid Excursion; EM: Epiglottic Movement; LVM: Laryngeal Vestibular Closure; PSW: Pharyngeal Stripping Wave; PC: Pharyngeal Contraction; PESO: Pharyngo Esophageal Segment Opening; TBR: Tongue Base Retraction; PR: Pharyngeal Residue; EC: Esophageal Clearance)

Figure 6 shows the percentage of participants in Group II with specific score in each oral, pharyngeal and esophageal component assessed during swallow of thin liquid (water). It can be concluded that most of the participants exhibited mild to moderate oral deficits. Among the oral deficits, lip closure was least affected for persons with MND. In spite of functional bolus transport in majority of the participants, oral residue was found to be significantly great with majority of the bolus remaining within the oral cavity. More than seventy percentage of the population had a delayed initiation of pharyngeal swallow reflex. Pharyngeal phase of swallowing was initiated when the bolus head was at the pyriformsinus in majority of the participants (Score 3).

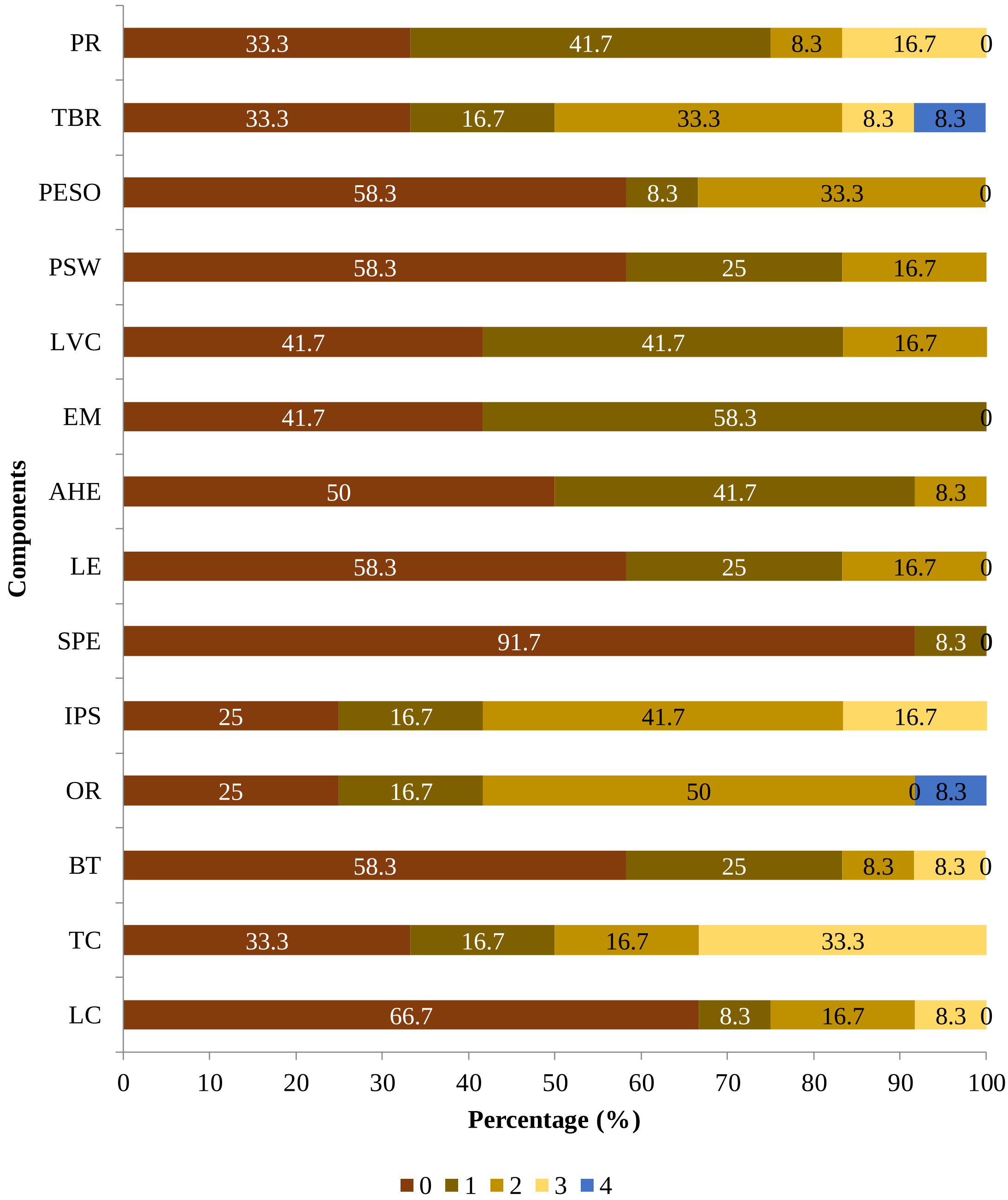

*Figure 6.*Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of thin liquid (Water) for Group II.

Pharyngeal components showed a mild to moderate impairment in nearly fiftypercentage of the participants. However, soft palate movement remained intact in ninetypercentage of the individuals indicating minimal or no nasal regurgitation in these individuals. Other airway protection mechanisms such as laryngeal elevation (LE), anterior hyoid excursion (AHE) and esophageal movement (EM) revealed that nearly half of theparticipants had a good airway protection mechanism (Score 0) whereas others had a partially efficient airway closure mechanism indicated by a moderate impairment score of 1. Other pharyngeal functions such as the pharyngeal stripping wave (PSW), the UES opening (PESO) and tongue base retraction (TBR) were also found to be partially impaired (Score 1). Overall, the pharyngeal phase efficiency was mildly impaired resulting in trace residue in the pharyngeal structures post swallow of thin liquids.

Next thicker consistency considered for analysis was nectar-thick liquid (rice starch). From the figure 7, it may be inferred that similar performance scores as thin liquid (water) were found when nectar was used. However, additional inferences regarding pharyngeal contraction could be drawn in this consistency as the recordings were taken in the antero-posteral view. It was found that majority of participants had an incomplete pharyngeal contraction leading to pharyngeal residue at various locations in the pharyngeal cavity. Pharyngeal efficiency however did not seem to vary much with increase in consistency of the medium. Esophageal function (EC) which was an additional component measured in this consistency, was found to be impaired in at least fifty percent of the participants, with an impairment score ranging from mild to moderate (Score 1 and 2). This indicated that many of the participants had a difficulty in clearing the bolus with a mild to moderate retention when thicker consistencies were presented.

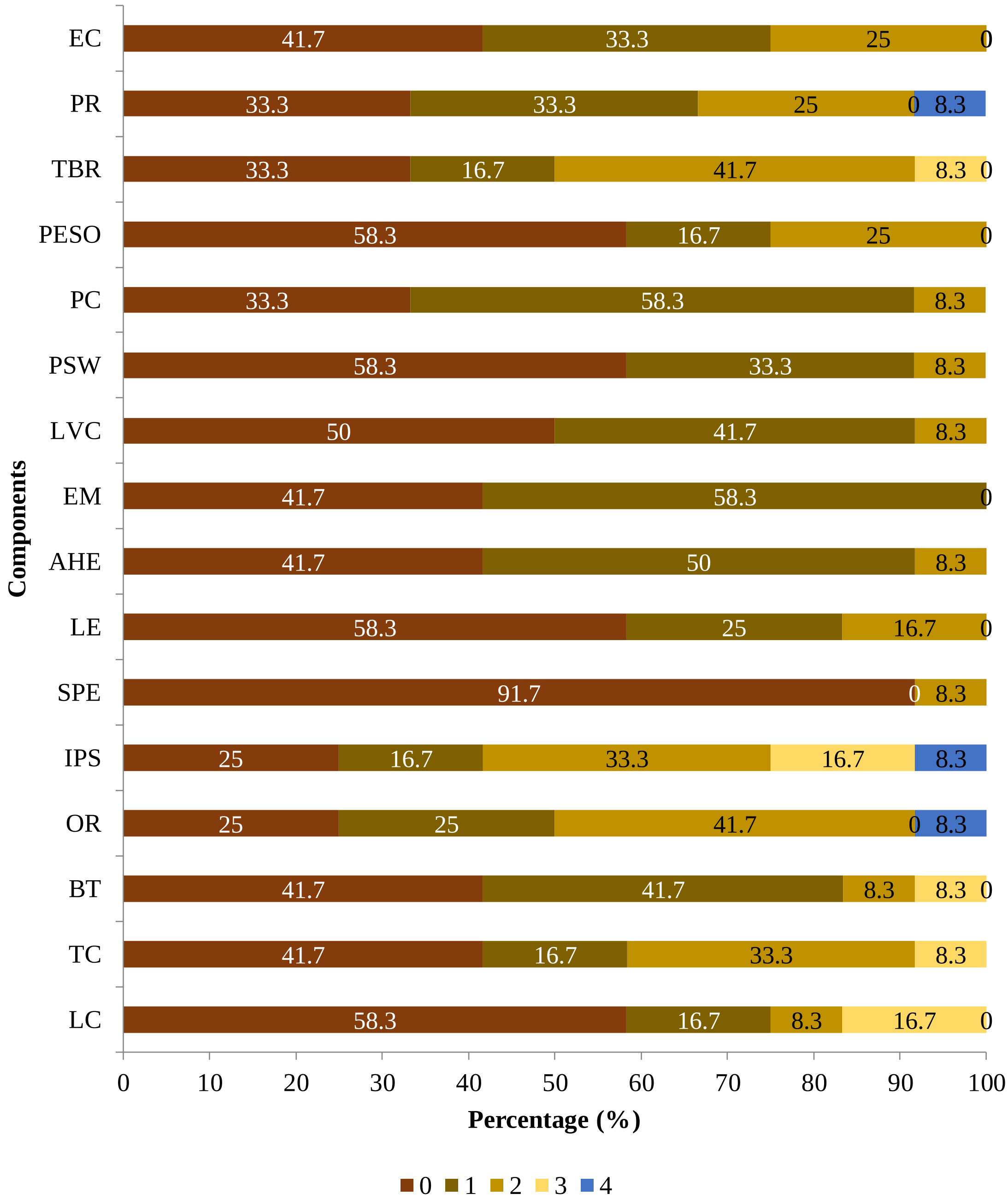

Figure7. Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of Nectar- thick liquid (Rice starch) for Group II.

Figure 8 summarizes the component score for honey thick consistency (honey) in each oral, esophageal and pharyngeal stages of swallowing. Similar performance was noted for the component scores for the oral components. However, with an increase in the consistency, oral residue seemed to have a significant effect. At least ninety percent of the participants had mild to moderate impairments with half of the residue remaining within the oral cavity.

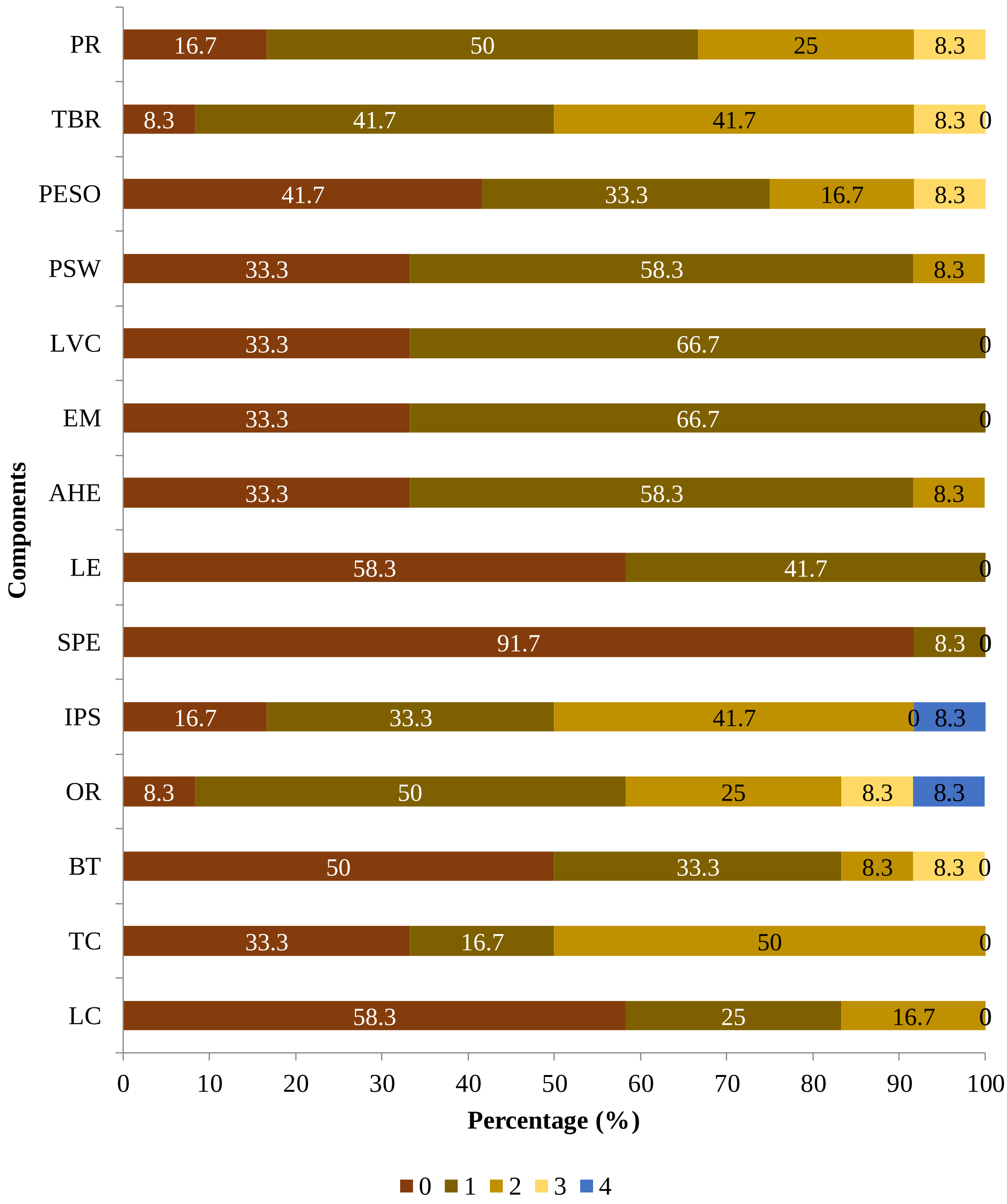

Figure 8. Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of honey -thick liquid (Honey) for Group II.

This could be because the thicker consistencies would be more cohesive that flows with lesser velocity through the oro-pharyngo-esophageal system and requires higher pressure drive for transport therefore leading to increased oral residue. Though pharyngeal scores were similar across the three liquid consistencies, mild effect of the increase in consistency can be noted across the scores of airway protection components as the participant percent scores increased for anterior hyoid excursion (AHE), epiglottic movement (EM), laryngeal vestibular closure (LVC), tongue base retraction (TBR) and pharyngeal residue (PR).

Similar interpretations could be made from figure 9 for swallow of semisolids (pudding). Inter-labial escape was found to be reduced with increase in the bolus consistency as the percent population score for adequate lip closure increased to as high as 67% (Score 0). However, bolus transport was found to have more impairment as the consistency of the medium was increased with the scores ranging from 2-4 for more than half of the participants. Pharyngeal components showed a greater effect of bolus consistency as the seen from the figure. It may be inferred that airway protection scores such as the laryngeal elevation (LE), anterior hyoid excursion (AHE), epiglottic movement (EM), laryngeal vestibular closure (LVC) showed moderate level of impairments (Score 1,2) in majority of the participants. Other pharyngeal components such PSW, PESO, TBR and PR also indicated an increase in impairment scores when pudding consistency (soaked biscuits) was used. This indicated that more number of participants had difficulty of varying degree to transport the thicker bolus through the pharyngeal stage for swallow, probably contributing to the higher PR score.

Bolus preparation (BP) was one component that was measured only for solid bolus (Biscuit). From the figure 10, it is evident that more than 70 percent of the participants in the group II had difficulty with timely and efficient chewing leading to increased oral phase time in delay in pharyngeal reflex initiation. Pharyngeal component scores were similar to semisolid consistency.

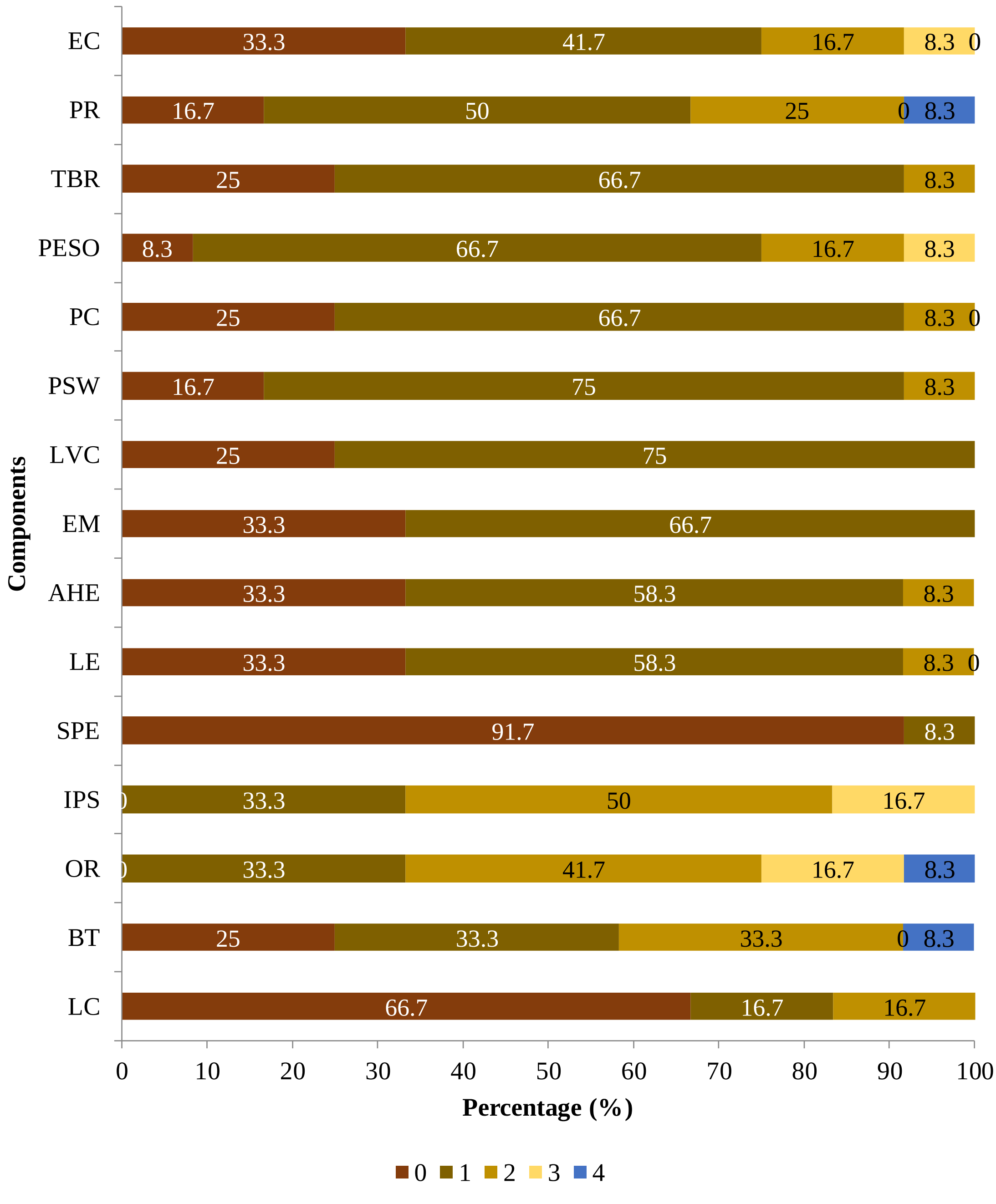

*Figure 9.*Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of pudding -thick solid (Soaked Biscuit) for Group II.

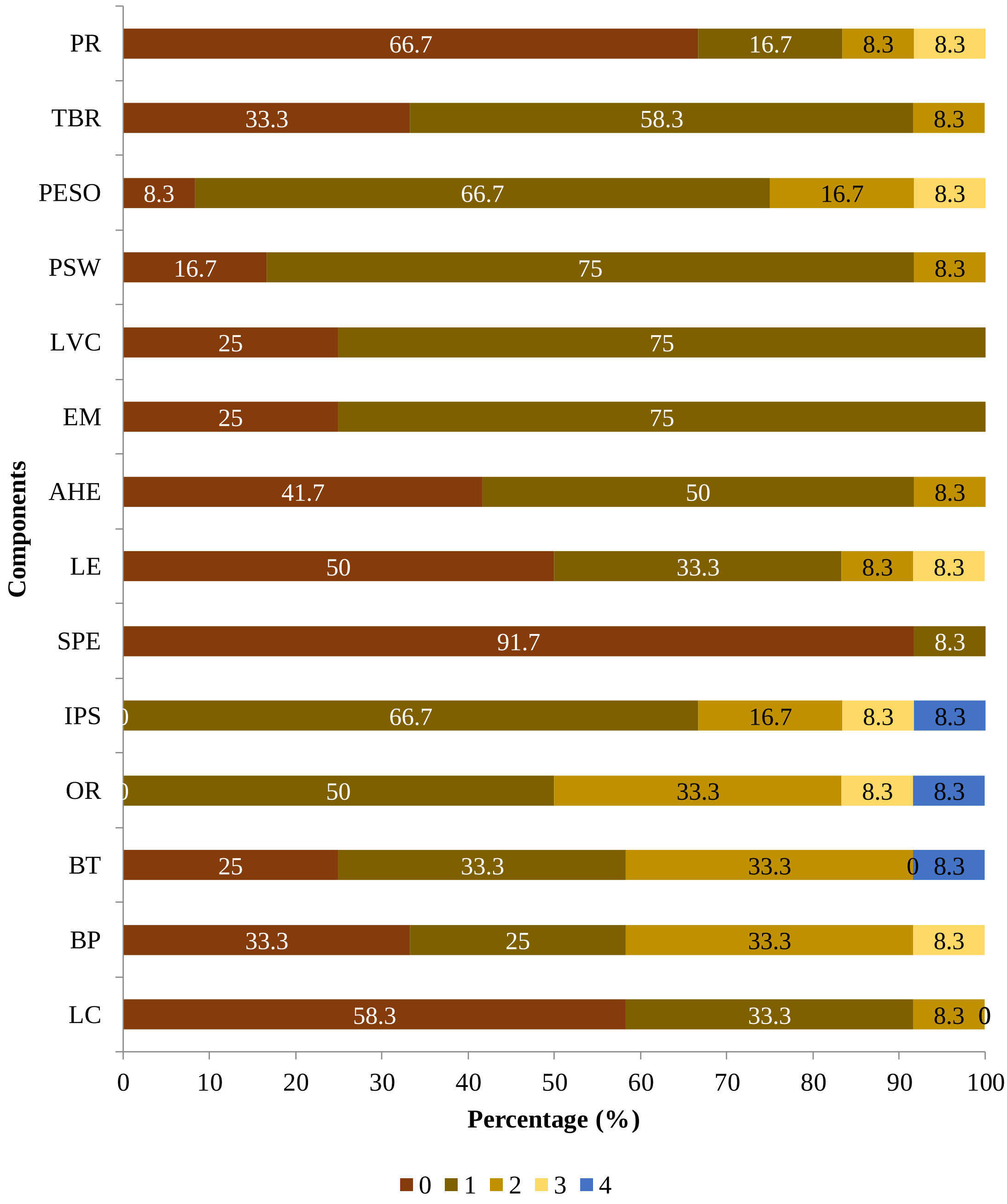

*Figure 10.*Percentage population with specific score in each oral, pharyngeal and esophageal component assessed during swallow of solid bolus (Biscuit) for Group II.

Compiling the information from Table 5 and Figures (6-10) it could be concluded that most of the physiologic component scores remained similar irrespective of the bolus consistency except for bolus transport (BT), anterior hyoid excursion (AHE), laryngeal vestibular closure (LVC) and pharyngeal stripping wave (PSW). These componentsshowed an increase in scores with consistency.

Concluding from the detailed data of group II (Table 5 & Figures 6-10) revealed that the overall impairment scores in Group II of this study were lesser compared to group I. Component scores of LC, TC, SPE and LE were the least and also independent of variations in bolus consistency. Hence, these functions were within normal limits during swallow of all bolus consistencies. The component scores of EM, PC and PR was also independent of bolus consistency suggesting that these functions do not adapt to consistency changes. Whereas BT, AHE, LVC, PSW, PESO and EC scores increased, IPS and TBR scores decreased with increasing bolus consistency. Similar to group I, score of IPS was the highest in majority of participants in group II. Unlike in group I, esophageal component scores were mildly impaired during swallow of nectar consistency. Therefore, null hypotheses for objective 1 is partially rejected in post stroke and MND population with dysphagia.

The observations made from above sections provide some insight to the altered physiology of swallow in individuals with dysphagia post stroke and post onset of MND. The present study observed that the function of lip closure (LC) was impaired only in post stroke population during swallow of thin bolus, indicating that lip weakness and anterior spillage is not a common finding in persons with persistent dysphagia post stroke or MND. If present, it presented with mild severity with inter-labial escape not extending beyond the anterior lips. This finding contradicts with the findings of Daniel et.al (1998) and Kumar et.al. (2012) reported in literature. Probably, lip weakness is more common in the acute stroke phase (Daniel et.al., 1998) and may recover near completely over time as in the present study. Interestingly, the MND population involved in this study also did not show significant lip weakness for swallow function, though bulbar onset MND is known to affect all oral structures (Robbins, 1987; Walshe, 2014). From the findings of this study, lip strength seems to be spared from degenerative changes in the subjects included in our sample.

Tongue function was assessed in the form of tongue strength for bolus hold (TC) and its movement for propulsion of bolus into the pharyngeal cavity (BT). The findings suggest that it is the movement rather than the strength that is impaired in both the groups of neurogenic dysphagia. Similar reports on lingual incoordination during swallow in stroke and MND has been reported previously also (Daniels, Brailey&Foundas, 1999; Ertekin, Aydogdu, Yüceyar, Kiylioglu, Tarlaci&Uludag, 2000; González-Fernández, Ottenstein, Atanelov, & Christian, 2013; Kawai et.al., 2013; Walshe, 2014). Significantly longer stage transition duration reported by Kim and McCollogh (2007) in post stroke population may be related to these disorganized movements of anterior and posterior part of tongue as observed here.

Mild to moderate difficulty in chewing could be observed in both post stroke and MND with minimal chewing and mashing of solid bolus that left pieces of unchewed bolus in the oral cavity. Breaking down the solid food for swallow also requires lingual coordination for positioning the bolus within the oral cavity and also for mixing the food with saliva (de Wijk, Prinz, Engelen, &Weenen, 2004; Blissett, Prinz, Wulfert, Taylor, &Hort, 2007; Alsanei, & Chen, 2014). Hence, chewing inefficiency may also be a combined output of lingual and masticatory weakness. Similar observations have also been reported previously (Westergren, Karlsson, Andersson, Ohlsson, & Hallberg, 2001; Perry & McLaren, 2003; Westergan, 2006; Walshe, 2014).

In spite of relatively preserved function of lip closure and tongue control, proportion of oral residue of the ingested bolus increased with bolus consistency, probably due to deficits in bolus transport. Literature review suggests that the proportion of oral residue is higher in neurologic dysphagia (Clave et al., 2006; Fattori et.al., 2006; Walshe, 2014).

Inferring from the observations made in the current study with that postulated by Kawai et.al. (2013) in MND population, difficulties in bolus transport rather than bolus hold seems to be the root cause of oral phase inefficiencies leading to oral residue (OR).

It is postulated that the difference in tongue motion is what elicits a swallow reflex rather than a gag reflex when food passes the anterior faucial pillars (Logemann, 1985). Therefore, the impaired lingual coordination may also contribute in impaired initiation of swallow reflex. This event marks the end of voluntary oral stage and beginning of the involuntary pharyngeal stage. In both the clinical groups studied, initiation of pharyngeal swallow reflex was the most severe and common impairment among the 17 components assessed in this study. In both stroke and MND population involved, the swallow was triggered past posterior angle of ramus, unlike in typical individuals (Dodds, Stewart, &Logemann, 1990; Logemann, 1998; Matsuo & Palmer, 2008). Further, lingual incoordination may lead to posterior spillage of the bolus into the pharyngeal cavity (Shapiro, 2000; Matsuo & Palmer, 2008). This delay in initiation of swallowing reflex is commonly reported in post stroke (Bisch, Logemann, Rademaker, Kahrilas& Lazarus, 1994; Bingjie, Tong, Xinting, Jianmin&Guijun, 2010) and MND (Ertekin et.al., 2000; Clave et.al., 2006) literature. The trigger is pulled by the sensory branches of cranial nerve IX that sends the afferent information to the reticular system in brainstem to initiate the motoric swallow sequence such as the velar elevation, laryngeal elevation, pharyngeal stripping wave and upper esophageal sphincter opening (Logemann, 1983). Neuroscience has not yet fully decoded the characteristics of this afferent information sent or received at the reticular site for initiating the swallow. However, difference in the measures of motoric sequence initiated by the swallow reflex suggests that the afferent information may include characteristics of the food being passed into the pharyngeal tract (Dantas et.al., 1990; Taniguchi, Tsukada, Ootaki, Yamada, & Inoue, 2008; Tsukada, Taniguchi, Ootaki, Yamada & Inoue, 2009; Humbert et.al., 2009; Chen, &Lolivret, 2011; Steele at.al., 2015). Failure, delay or inappropriate integration of this information into the swallowing sequence may alter the motoric algorithm of pharyngeal swallow. Therefore in the present study, the impaired measures of pharyngeal components (LE, AHE, EM, LVC, PSW, PC, & PES) may be sequel of impaired initiation of pharyngeal swallow reflex. Altered functioning at this components were also reported previously by many researchers in various contexts (Leighton, Burton, Lund & Cochrane, 1994; Ertekin et.al, 2000; Martino, Terrault, Ezerzer, Mikulis, & Diamant, 2001;Kawai et.al., 2003; Clave et al., 2006; Bian, Choi, Kim, Han & Lee, 2009; Argolo, Sampaio, Pinho, Melo &Nobrega, 2015;Ellerston, Heller, Houtz& Kendall, 2016; Solazzo et. al., 2016). However, the neuropathology for this impairment may be different in stroke and MND considering the site and nature of lesion in these two conditions. Evidence for this statement may be derived from the observation that the delay in initiation of pharyngeal swallow seemed to reduce with bolus consistency in post stroke but not in MND. However, this observation requires further validation. Apart from the swallowing reflex, alterations are also reported in the initiation of cough and gag reflex networks in neurological dysphagia (Terré&Mearin, 2006; Somasundaram, 2014).

Among the motoric sequences in the pharyngeal cavity, elicited by the pharyngeal swallow reflex, soft palate elevation seemed the least interfered. All the participants in the study sealed the naso-pharynx effectively preventing the bolus from nasal penetration. This is in contradiction to the reports of Terre and Mearin (2006) who reported that at least 3% of acute post stroke individuals had velo-pharyngeal insufficiency during swallowing act when evaluated within 3 months of onset. Also, naso-pharyngeal penetration was reported to be a common impairment in persons diagnosed with MND in the study by Ertekin et.al. (2000) but was not observed in the participants of this study.

In typical swallows, tongue base retraction brought by the activity of hyoglossus and styloglossus muscles and its posterior pharyngeal wall contact is thought to provide a thrust to bolus transport during swallow (Gassert& Pearson, 2016). Apart from improving the velocity of bolus through the pharyngeal cavity, its role in triggering the pharyngeal swallow sequence is also well documented (Broussard &Altschuler, 2000; Pauloski&Logemann, 2000; Kitagawa, Shingai, Takahashi, & Yamada, 2002; Kawai et.al., 2003; Logemann, 2007). However, the same measure was found to be most severely impaired in the pharyngeal phase in both post stroke and MND population in the current study. Ertekin, Aydogdu, Yuceyar, Kiylioglu, Tarlaci, and Uludag (2000) had found prolonged electromyographic potentials of laryngeal elevator muscles among which hyoglossus was one, supporting the finding of reduced tongue base retraction in persons diagnosed with MND. A narrow column of air between the root of the tongue and posterior pharyngeal wall can reduce the driving force on bolus passing through the pharyngeal cavity, thereby increasing the pharyngeal transit time (Fattori et.al, 2006). Also reduced tongue to posterior pharyngeal wall contact may contribute to reduced pharyngeal clearance component (PR) and airway protection components (LE,AHE, EM, LVC) as was established by the findings of Pauloski and Logemann (2000) in persons with head and neck cancer.

Pharyngeal residue (PR) component is associated with tongue base retraction (Pauloski&Logemann, 2000) and also the upper esophageal sphincter opening (PESO) (Terre &Mearin, 2006). This indicated the overall efficiency of pharyngeal swallow (Logemann, Williams, Rademaker, Pauloski, Lazarus & Cook, 2005) and was found to be moderately impaired in stroke (Terre &Mearin, 2006) but only mildly impaired in MND population (Leighton, Burton, Lund & Cochrane, 1994; Wright & Jordan, 1997;Clave et al., 2006;Argolo, Sampaio, Pinho, Melo &Nobrega, 2015). The central lesion in post stroke population may result in incoordination of pharyngeal swallow sequence leading to reduced pharyngeal efficiency in clearing the bolus. However, the MND population in this study had mild presentation of pharyngeal residue, probably as in the initial stages of the condition. This is in consensus with the manometric changes identified in the oro-pharyngeal area by Higo, Tayama, Watanable and Nitou (2002).

Atypical peristaltic movement of esophagus and alterations in the measures of peristaltic contractions in post stroke has been reported (Weber et. al., 1991; Micklefield, Jorgensen, Blaeser, Jorg&Kobberrling, 1999). The present study only looked into the functional efficiency of this stage with esophageal clearance (EC) being the esophageal stage component included. In post stroke population, a bolus consistency dependent reduction in esophageal transit was found by Silva, Fabio and Dantas (2008) wherein a reduction in the transit time compared to typical swallows was reported for liquid consistency. This study also found no difference in esophageal residue in post stroke dysphagia. The findings of the present study is in congruence with this findings as the esophageal clearance (EC) was not impaired suggesting that the dysphagia is primarily oro-pharyngeal in post stroke (Weber et.al., 1991; Kidd, Lawson, Nesbitt &MacMahon, 1993; Mann, Hankey & Cameron, 1999; Micklefield, Jorgensen, Blaeser, Jorg&Kobberrling 1999;Rofes, Vilardell& Clave, 2013) and MND (Roller et al., 1974; Carpenter et al., 1978; Briani et.al., 1998; Kawai et.al., 2003; Fattori et al., 2006; Paris et.al., 2013; Walshe, 2014).

Comparison of MBSImp^{TM} component scores across group I and group II in each bolus consistency.

The scores obtained for each component during swallow of each bolus consistency was compared across group I and group II using non-parametric comparison methods. Table 6 provides the mean, median and standard deviation of component scores in group I and group II for each bolus consistency included in the study. This data was run with Mann-

Whitney U-test for comparison of mean and results revealed the statistical significance of differences noticed in the component scores across the two groups.

Table 6.

Mean, Median and Standard Deviation of component scores for each bolus consistency in Group I and Group II.

Parameters	**Consistencies Used**	**Group I**			**Group II**		
		Mean	Median	Standard deviation	Mean	Median	Standard deviation
LC	Water	1.00	1.00	0.92	0.67	0.00	1.07
	Nectar	0.87	1.00	0.99	0.83	0.00	1.19
	Honey	0.53	0.00	0.83	0.58	0.00	0.79
	Pudding	0.53	0.00	0.74	0.50	0.00	0.79
	Solid	0.20	0.00	0.41	0.50	0.00	0.67
TC	Water	0.93	1.00	0.79	1.50	1.50	1.31
	Nectar	1.13	1.00	0.74	1.08	1.00	1.08
	Honey	1.00	1.00	0.84	1.17	1.50	0.93
BP	Solid	1.40	1.00	0.82	1.17	1.00	1.03
BT	Water	0.93	1.00	1.10	0.67	0.00	0.98
	Nectar	0.93	1.00	1.03	0.83	1.00	0.93
	Honey	0.80	0.00	1.01	0.75	0.50	0.96
	Pudding	1.33	1.00	1.23	1.33	1.00	1.15
	Solid	1.00	1.00	0.84	1.33	1.00	1.15
OR	Water	1.47	1.00	0.83	1.50	2.00	1.16
	Nectar	1.40	1.00	0.82	1.42	1.50	1.16
	Honey	1.60	2.00	0.73	1.58	1.00	1.08
	Pudding	1.87	2.00	0.83	2.00	2.00	0.95
	Solid	2.00	2.00	0.84	1.75	1.50	0.96
IPS	Water	1.80	2.00	1.20	1.50	2.00	1.08
	Nectar	1.87	2.00	0.91	1.67	2.00	1.30
	Honey	1.87	2.00	0.74	1.50	1.50	1.08
	Pudding	1.87	2.00	0.83	1.83	2.00	0.71
	Solid	1.67	2.00	0.72	1.58	1.00	0.99
SPE	Water	0.20	0.00	0.41	0.08	0.00	0.28
	Nectar	0.20	0.00	0.56	0.17	0.00	0.57
	Honey	0.20	0.00	0.56	0.08	0.00	0.28
	Pudding	0.13	0.00	0.35	0.08	0.00	0.28
	Solid	0.13	0.00	0.35	0.08	0.00	0.28
LE	Water	0.60	1.00	0.50	0.58	0.00	0.79
	Nectar	0.53	1.00	0.51	0.58	0.00	0.79
	Honey	0.40	0.00	0.50	0.42	0.00	0.51
	Pudding	0.33	0.00	0.48	0.75	1.00	0.62
	Solid	0.33	0.00	.048	0.67	1.00	0.65

AHE	Water	0.53	0.00	0.64	0.58	0.50	0.66
	Nectar	0.53	1.00	0.51	0.67	1.00	0.65
	Honey	0.47	0.00	0.51	0.75	1.00	0.62
	Pudding	0.40	0.00	0.50	0.75	1.00	0.62
	Solid	0.40	0.00	0.50	0.67	1.00	0.65
EM	Water	0.60	1.00	0.50	0.58	1.00	0.51
	Nectar	0.60	1.00	0.50	0.58	1.00	0.51
	Honey	0.73	1.00	0.59	0.67	1.00	0.49
	Pudding	0.73	1.00	0.70	0.67	1.00	0.49
	Solid	0.80	1.00	0.67	0.75	1.00	0.45
LVC	Water	0.80	1.00	0.41	0.75	1.00	0.75
	Nectar	0.87	1.00	0.35	0.58	0.50	0.66
	Honey	0.93	1.00	0.25	0.67	1.00	0.49
	Pudding	1.07	1.00	0.45	0.75	1.00	0.45
	Solid	1.07	1.00	0.45	0.75	1.00	0.45
PSW	Water	0.67	1.00	0.48	0.58	0.00	0.79
	Nectar	0.67	1.00	0.48	0.50	0.00	0.67
	Honey	0.80	1.00	0.41	0.75	1.00	0.62
	Pudding	0.80	1.00	0.41	0.92	1.00	0.51
	Solid	0.87	1.00	0.35	0.92	1.00	0.51
PC	Nectar	0.73	1.00	0.45	0.75	1.00	0.62
	Pudding	1.00	1.00	0.37	0.83	1.00	0.57
PESO	Water	0.87	1.00	0.74	0.75	0.00	0.96
	Nectar	1.07	1.00	0.88	0.67	0.00	0.88
	Honey	1.07	1.00	0.79	0.92	1.00	0.99
	Pudding	1.40	1.00	0.63	1.25	1.00	0.75
	Solid	1.33	1.00	0.61	1.25	1.00	0.75
TBR	Water	1.40	2.00	0.91	1.42	1.50	1.31
	Nectar	1.53	2.00	0.74	1.25	1.50	1.05
	Honey	1.40	1.00	0.73	1.58	1.50	0.99
	Pudding	1.73	2.00	0.70	1.83	2.00	0.57
	Solid	1.67	2.00	0.61	1.75	2.00	0.62
PR	Water	1.33	1.00	0.81	1.08	1.00	1.08
	Nectar	1.40	1.00	0.63	1.17	1.00	1.19
	Honey	1.67	2.00	0.97	1.25	1.00	0.86
	Pudding	2.00	2.00	0.65	1.33	1.00	1.07
	Solid	1.87	2.00	0.74	1.58	1.00	0.99
EC	Nectar	0.47	0.00	0.64	0.83	1.00	0.83
	Pudding	0.40	0.00	0.63	1.00	1.00	0.95

(*Note:*. LC: Lip Closure; TC: Tongue Control during bolus hold; BP: Bolus Preparation; BT: Bolus Transport; OR: Oral Residue; IPS: Initiation of Pharyngeal Swallow; SPE: Soft Palate Elevation; LE: Laryngeal Elevation; AHE: Anterior Hyoid Excursion; EM: Epiglottic Movement; LVM: Laryngeal Vestibular Closure; PSW: Pharyngeal Stripping Wave; PC: Pharyngeal Contraction; PESO: Pharyngo Esophageal Segment Opening; TBR: Tongue Base Retraction; PR: Pharyngeal Residue; EC: Esophageal Clearance)

There was no statistically significant difference in the scores of oral (LC: $|Z| = 1.18$, $p > 0.05$; TC: $|Z| = 1.11$, $p > 0.05$; BT: $|Z| = 0.66$, $p > 0.05$; OR: $|Z| = 0.12$, $p > 0.05$) or pharyngeal (IPS: $|Z| = 0.75$, $p > 0.05$; SPE: $|Z| = 0.83$, $p > 0.05$; TBR: $|Z| = 0.12$, $p > 0.05$; LE: $|Z| = 0.40$, $p > 0.05$; AHE: $|Z| = 1.19$, $p > 0.05$; EM: $|Z| = 0.08$, $p > 0.05$; LVC: $|Z| = 0.43$, $p > 0.05$; PSW: $|Z| = 0.68$, $p > 0.05$; PESO: $|Z| = 0.52$, $p > 0.05$; PR: $|Z| = 0.93$, $p > 0.05$) components of swallow across group I and group II during swallow of thin liquids (Water).Pharyngeal contraction and esophageal component could not be analyzed during swallow of thin liquid as this was not a part of the protocol of MBSImp. Similarly, the two groups had comparable performance in oral (LC: $|Z| = 0.31$, $p > 0.05$; TC: $|Z| = 0.23$, $p > 0.05$; BT: $|Z| = 0.18$, $p > 0.05$; OR: $|Z| = 0.02$, $p > 0.05$), pharyngeal (IPS: $|Z| = 0.48$, $p > 0.05$; SPE: $|Z| = 0.35$, $p > 0.05$; TBR: $|Z| = 0.67$, $p > 0.05$; LE: $|Z| = 0.13$, $p > 0.05$; AHE: $|Z| = 0.47$, $p > 0.05$; EM: $|Z| = 0.08$, $p > 0.05$; LVC: $|Z| = 1.57$, $p > 0.05$; PSW: $|Z| = 0.97$, $p > 0.05$; PC: $|Z| = 0.03$, $p > 0.05$; PESO: $|Z| = 1.21$, $p > 0.05$; PR: $|Z| = 0.06$, $p > 0.05$) and esophageal components (EC: $|Z|$: 1.18, $p > 0.05$) during swallow of nectar thick liquids. Similar findings could also be observed from the results during swallow of honey thick (LC: $|Z| = 0.22$, $p > 0.05$; TC: $|Z| = 0.52$, $p > 0.05$; BT: $|Z| = 0.05$, $p > 0.05$; OR: $|Z| = 0.47$, $p > 0.05$; IPS: $|Z| = 1.17$, $p > 0.05$; SPE: $|Z| = 0.44$, $p > 0.05$; TBR: $|Z| = 0.42$, $p > 0.05$; LE: $|Z| = 0.08$, $p > 0.05$; AHE: $|Z| = 1.19$, $p > 0.05$; EM: $|Z| = 0.23$, $p > 0.05$; LVC: $|Z| = 1.73$, $p > 0.05$; PSW: $|Z| = 0.36$, $p > 0.05$; PESO: $|Z| = 0.61$, $p > 0.05$; PR: $|Z| = 1.20$, $p > 0.05$) and solids (LC: $|Z| = 1.28$, $p > 0.05$; BP: $|Z| = 0.64$, $p > 0.05$; BT: $|Z| = 0.64$, $p > 0.05$; OR: $|Z| = 0.97$, $p > 0.05$; IPS: $|Z| = 0.70$, $p > 0.05$; SPE: $|Z| = 0.40$, $p > 0.05$; TBR: $|Z| = 0.35$, $p > 0.05$; LE: $|Z| = 1.39$, $p > 0.05$; AHE: $|Z| = 1.08$, $p > 0.05$; EM: $|Z| = 0.08$, $p > 0.05$; LVC: $|Z| = 1.71$, $p > 0.05$; PSW: $|Z| = 0.25$, $p > 0.05$; PESO: $|Z| = 0.58$, $p > 0.05$; PR: $|Z| = 1.29$, $p > 0.05$). The only component that showed significant difference was the PR ($|Z| = 2.27$, $p < 0.05$) during swallow of pudding consistency and all other component score were comparable across the two groups (LC: $|Z| = 0.22$, $p > 0.05$; BT: $|Z| = 0.02$, $p > 0.05$; OR: $|Z| = 0.34$, p

>0.05; IPS: |Z|= 0.05,*p*>0.05; SPE: |Z|= 0.40, *p* >0.05; TBR: |Z|= 0.49, *p* >0.05; LE: |Z|= 1.80, *p* >0.05; AHE: |Z|= 1.49, *p* >0.05; EM: |Z|= 0.11, *p* >0.05; LVC: |Z|= 1.71, *p* >0.05; PSW: |Z|= 0.60, *p* >0.05; PC: |Z|=0.94, *p* >0.94; PESO: |Z|= 0.85, *p*>0.05; EC: |Z|= 1.82, *p*>0.05). As seen in Table 6, the PR component score was significantly higher for group I compared to group II. Therefore, the null hypotheses was accepted for all components in the thin-liquid, nectar-thick liquid, honey-thick liquid, solid and pudding consistency except the pharyngeal residue score in pudding consistency bolus.

The findings of the present study suggested that the two leading causes of dysphagia do not differ in its presentation of physiological impairments during swallow. Therefore, the components of physiological swallow assessment in persistent dysphagia can be similar across the two major causes of dysphagia, i.e. stroke and MND.

Although most of the components exhibited comparable levels of physiological dysfunction, functional outcome of pharyngeal phase of swallow showed statistically significant differences in the present study. The pharyngeal residue measure was found to be significantly higher in stroke compared to MND. Pharyngeal residue indicates impairment in the oro-pharyngeal striving force on the passing bolus. This measure has been evaluated for its validity and is consented as the one measure that determined oro-pharyngeal swallow efficiency (Logemann, Williams, Rademaker, Pauloski, Lazarus, & Cook, 2005; Rademaker,Pauloski, Logemann, &Shanahan, 1993; Kelly, Leslie, Beale, Payten, &Drinnan, 2006). In typical swallows as well, viscous boluses passed with less efficiency (Hamlet, Muz, Farris, Kumpuris, & Jones, 1992; Hamlet, Choi, Zormeier, Shamsa, Stachler, Muz, & Jones, 1996) suggesting the oral residue measure is typically bolus dependent. The findings of the present study also supported this finding with higher pharyngeal residue in pudding consistency in the post stroke population. However, the study of Clave (2006) found that improving bolus consistency to pudding improved swallow efficiency, which contrast with the observations made in this study. The finding from current research may also suggest that oro-pharyngeal efficiency is more compromised in central lesion compared to the peripheral.This is also in contrast to the findings of Clave et.al. (2006) who reported efficacy was more compromised in neuro-degenerative conditions compared to non-progressive brain damage conditions such as that of stroke.

Comparison of MBSImp^{TM} component scores across bolus consistencies in group I and group II

Friedman's test for comparison of means was run on the descriptive data (Table 6) for comparing the significance of differences noticed in the scores across the five bolus consistencies in each component. This comparison was expected to provide evidences for presence or absence of physiological adaptations for sensory information such as that of bolus consistency in persons with dysphagia. However, not all physiological components could be compared across consistency as the recording protocol limitations in the recording protocol. The results revealed that there were significant differencesin few components of MBSImpacross the bolus consistencies in Group I and Group II. Generally, the number of components that showed significant differences across consistencies were more in Group I compared to group II indicating better motoric adaptations to sensory variations in post stroke compared to MND.

In Group I, the oral stage components of LC ($\chi^2(4)$ =23.00; $p< 0.05$) and OR ($\chi^2(4)$=14.23; $p<0.05$) showed statistically significant differences. Wilcoxon's signed rank test was used for post hoc analysis of this data. The results are summarized in Figure 11. In this figure, the solid colored lines indicated a statistically significant difference across consistencies ($p < 0.05$) and dashed lines indicated absence of such difference ($p > 0.05$). The component LC differentiated broadly between Water and thick consistencies (Honey,

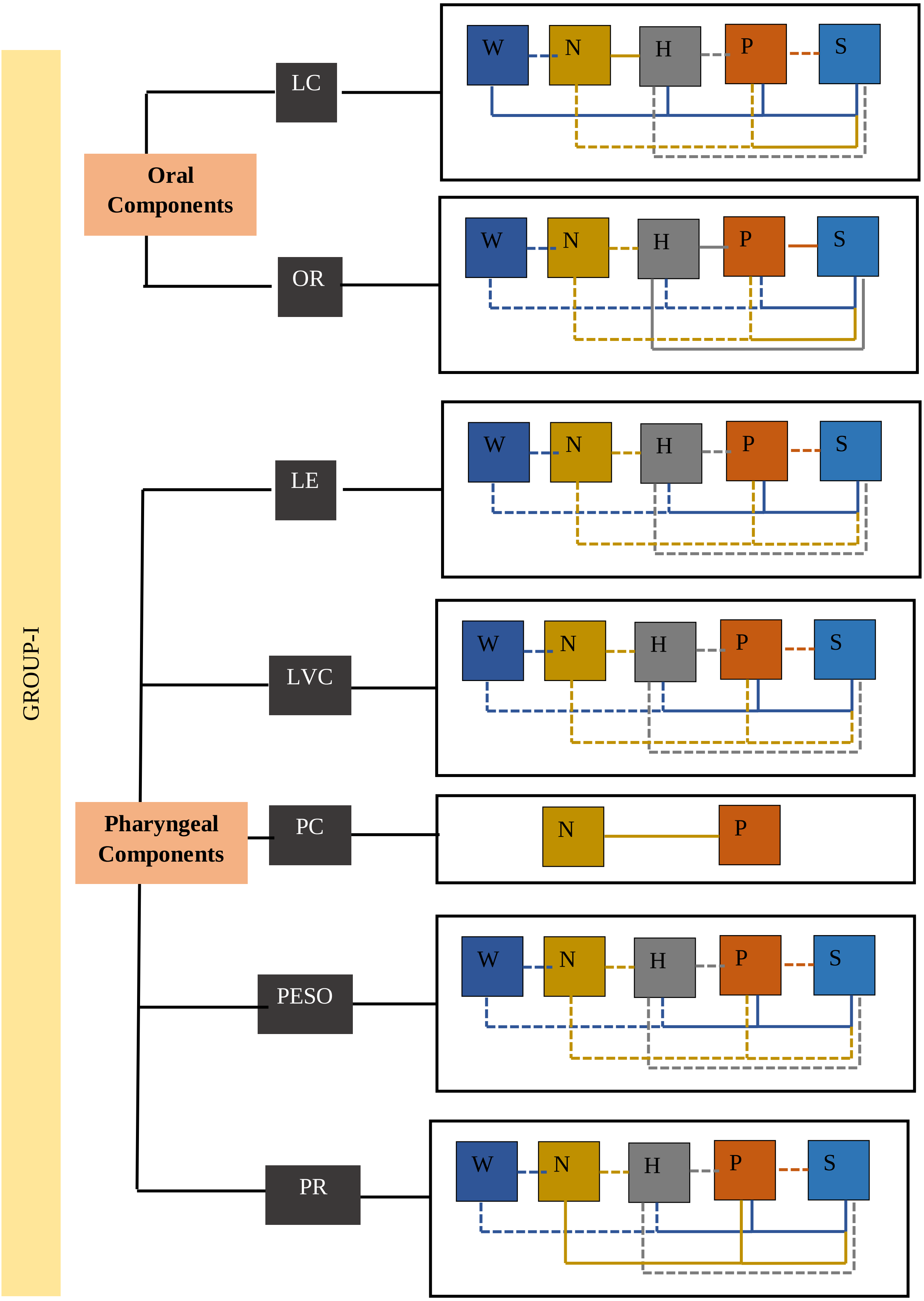

Figure 11: Comparison of component scores across bolus consistencies in Group I.

Pudding and Solid) but did not differentiate between subtle consistency difference such as that of Water and Nectar thick. The scores of LC in water and nectar thick consistencies are significantly higher compared to thicker consistency bolus in Group I participants. The component OR was less adaptive to these consistency differences compared to LC. The component OR differentiated Water, Nectar thick and Honey thick from higher consistency bolus such as pudding and solids. The oral residue showed significant increase with increasing bolus consistency. There. was no significant effect of bolus consistency in the component scores of TC ($\chi^2(4) = 0.89$; $p > 0.05$) and BT ($\chi^2(4) = 5.59$; $p > 0.05$) indicating that these components did not show significant adaptation to changes in bolus consistency in post stroke dysphagia

At the pharyngeal level, LE ($\chi^2 = 12.00$; $p < 0.05$), LVC ($\chi^2 = 11.63$; $p < 0.05$), PESO ($\chi^2 = 13.68$; $p < 0.05$), and PR ($\chi^2 = 19.01$; $p < 0.05$) showed statistically significant differences across bolus consistencies. The component PC was scored only during swallow of Nectar and Pudding consistency and it was found to be significantly different ($\chi^2 = 4.00$; $p < 0.05$). Results of post hoc analysis of these component scores using Wilcoxon's signed rank test is summarized in Figure 1. All the components except PR differentiated water consistency from Pudding and Solid consistencies. In addition to this, PR differentiated Nectar from Pudding and Solid consistencies. Other component scores such as IPS ($\chi^2(4) = 1.45$; $p > 0.05$), SPE ($\chi^2(4) = 1.33$; $p > 0.05$), AHE ($\chi^2(4) = 2.86$; $p > 0.05$), EM ($\chi^2(4) = 3.79$; $p > 0.05$), PSW ($\chi^2(4) = 8.00$; $p > 0.05$), and TBR ($\chi^2(4) = 6.71$; $p > 0.05$) failed to show statistically significant differences across bolus consistencies. Similar to the component PC, the esophageal component (EC) was scored only for Nectar and Pudding consistency as per the MBSImp guidelines. While PC showed significant differences, EC failed to show these differences across nectar and pudding consistency ($\chi^2(4) = 1.00$; $p > 0.05$). Therefore, the null hypotheses is partially accepted for each oral and pharyngeal component in group I across bolus consistencies.

Bolus adaptations to swallow are the changes incorporated into a measure in response to changes in bolus characteristics. Various objective measures are found to respond differently to bolus characteristics (Dodds, Man, Cook,Kahrilas, Stewart, & Kern, 1988; Piancino, Bracco, Vallelonga, Merlo,& Farina, 2008; Butler, Stuart, Castell, Russell, Koch, & Kemp, 2009; Hoffman, Ciucci, Mielens, Jiang & McCulloch, 2010) and these indicate sensory-motor integration in the motor-reflexive swallow pattern. From the findings of the present study, post stroke individuals seemed to have certain swallow functions that adapt while few other functions that fail to do the same. In the oral phase, lip closure function responded differentially to thin and other bolus consistencies with greater impairment in thin liquids. This suggested the greater role of lip closure in retaining the thin bolus in the oral cavity compared to thicker consistencies (Han, Paik & Park 2001; Hägg&Anniko, 2008). Tongue functions for bolus control, transport, base retraction and initiation of pharyngeal reflex failed to show bolus differentiations suggesting that the afferent information about the consistency of passing bolus is not incorporated into these motor patterns. This can turn disastrous as these functions are critical for timely and efficient transition from oral to pharyngeal phase of swallow. As seen in another section of this study, absence of this sensory motor integration may be the underlying reason for the greater impairment in the component that assessed initiation of pharyngeal reflex (IPS). Consequences of inappropriate integration were also discussed in detailed previously. Lowered efficiency of swallow was most evident for solid consistency with statistically significant higher oral residue (OR) for thicker consistency. This can be inferred as the result of poor adaptation of tongue movements that are required for efficiently transporting solid boluses from mouth to pharynx

(Shinagawaet.al.,2004; De Wijk, Terpstra, Janssen, & Prinz, 2006; Hori, Ono, &Nokubi, 2006; de Wijk, Janssen, & Prinz, 2011).

In the naso-pharynx, soft palate elevation did not show differential performance across bolus consistencies and from the Table 6, the component SPE performed with typical scores suggesting that irrespective of the bolus consistency, the naso-pharyngeal was decoupled effectively in post stroke participants. This is in contradiction to the reports that could be retrieved from literature (Hägg& Larsson, 2004; Terre &Mearin, 2006) and may be attributable to the post stroke duration considered in these studies. While pharyngeal contraction (PC) was consistency dependent with higher score for pudding consistency, Pharyngeal stripping wave (PSW) was not. This suggested that the pharyngeal driving force exerted with pharyngeal contraction on the thick boluses are impaired, probably resulting in weaker stripping for solid boluses making the component PSW less adapted to bolus characteristics. Few airway decoupling functions such as laryngeal elevation (LE) and laryngeal vestibular closure (LVC) showed significant differences across consistencies while other measures such as anterior hyoid movement and epiglottic movement were not consistency dependent. This suggests that these functions are differentially influenced by sensory information related to bolus consistency, probably because epiglottic movement and hyoid movements are more reflexive in nature than laryngeal elevation and closure. It is also possible that various components respond differentially to bolus information such as bolus volume, texture, and temperature (Dodds et.al., 1988). According to Ishida, Palmer, andHiiemae, (2002), anterior hyoid motion is related to the various pharyngeal processes. Therefore, altered pharyngeal response to consistency information may underlie the lack of adaptation in the anterior motion of this structure. Also, laryngeal elevation is known to be directly related to extent of UES opening (Kelly, 2000; Sivarao& Goyal, 2000; Yokoyama, Mitomi, Tetsuka, Tayama&Niimi, 2000; Shakeret.al.,2002). Therefore differential performance of UES in the current study may be attributed to preserved adaptation of laryngeal elevation function. Differences in objective measures of UES opening was reported in response to bolus volume by Jacob, Kahrilas,Logemann, Shah, and Ha (1989) as well as Kahrilas, Dodds, Dent, Logemann, and Shaker (1988). As a result of all the adaptations and maladaptations, pharyngeal residue is higher in thicker bolus compared to thin. The findings of the present study indicate that there are certain components of oral and pharyngeal stages of swallow that are susceptible to sensory variations than others. Future research should progress towards identifying these two function groups in typical and atypical individuals.

The current study suggests that in assessment of swallow safety in persistent dysphagia post stroke, VFSS recording protocol may be shortened to use of a thick consistency (Pudding/Solid) and thin consistency bolus (Water) rather than including the intermediate consistencies (Nectar thick and honey thick). This can further reduce the duration of radiation exposure in post stroke population. Therefore, efficiency of assessment protocols may be enhanced without compromising on swallowing function assessment. Assessment of the 17 components of swallow as per MBSImp in two consistencies (Water & Pudding/Solid) would then provide a comprehensive overview of the swallow safety in post stroke individuals.

Results of Friedmans's test on component scores in group II revealed that BT was the only oral component that had statistically different scores across bolus consistencies$\chi^2(4) = 16.86$; $p < 0.05$). Scores increased with increasing consistency in BT component indicating that group II participants had greater difficulty in transporting thick bolus from oral to pharyngeal structures. This component assessed the efficiency of bolus transport from mouth to pharynx and it differentiated between thin and thick boluses with greater impairment for solid boluses suggesting lingual weakness. Other component that assessed lingual function, TC, assessed tongue strength in holding the bolus in the mouth for swallow and did not show differences across bolus consistencies ($\chi^2(4) = 5.25$, $p > 0.05$). Other components LC ($\chi^2(4) = 4.98$, $p > 0.05$) and OR ($\chi^2(4) = 6.73$, $p > 0.05$) did not show significant differences across consistencies. Lingual involvement is observed to be one of the prime reasons for dysphagia in persons with bulbar onset MND (Kawai et.al., 2003; Walshe, 2014). The findings of the present study is in consensus with these reports but add on to the literature with the observation that it is the efficiency of tongue movement for swallow rather than strength that plays a role in oro-pharyngeal dysphagia in individuals with MND. Therefore, the proposition of Kawai et.al.(2003) that attributed oro-pharyngeal dysphagia to poor bolus transport by anterior tongue or poor bolus hold by posterior tongue is further explained. The findings of the present study suggest that it is the anterior tongue rather than the posterior that contributes to dysphagia in this population.

Among the pharyngeal phase components, PESO ($\chi^2(4)= 10.62$, $p < 0.05$) and PSW ($\chi^2(4) = 11.56$, $p < 0.05$) showed bolus adaptations but all other components (SPE: $\chi^2(4) =4.00$, $p > 0.05$; IPS: $\chi^2(4) = 3.59$, $p > 0.05$; TBR: $\chi^2(4) = 7.10$, $p > 0.05$; PC: $\chi^2(4) = 1.00$, $p > 0.05$; EM: $\chi^2(4) = 1.87$, p> 0.05; AHE: $\chi^2(4) = 5.60$, $p > 0.05$; LE: $\chi^2(4) = 5.87$, $p > 0.05$; LVC: $\chi^2(4) = 1.60$, $p > 0.05$; PR: $\chi^2(4) = 6.03$, $p > 0.05$) scores were statistically similar across bolus consistencies. The esophageal component also failed to show significant differences across the five bolus consistencies (EC: $\chi^2(4) = 2.00$, $p > 0.05$). Post hoc analysis using Wilcoxon' s sign rank test revealed the consistencies differentiated by each component. This analysis revealed that all the three components (BT, PESO and PSW) differentiated water, nectar and honey thick bolus from pudding and solid boluses. This differentiation was less conclusive in PSW with no significant difference in scores from Honey thick to pudding and solid consistency boluses. The component BT was found to have higher scores on thicker consistency boluses, whereas PESO and PSW was more affected with thin consistency. The results of Wilcoxons sign rank test is summarized in figure 2. In this figure, the solid colored lines indicated a statistically significant difference across consistencies ($p < 0.05$) and dashed lines indicated absence of such difference ($p > 0.05$). Therefore, the null hypotheses is partially accepted for each oral and pharyngeal component in group II across bolus consistencies.

As evident from the results of the present study, there was lesser number of swallowing physiological components in persons with MND that showed perceivable differences to bolus consistency changes. Though impairments in sensory integration to motor algorithms of swallow is a prime suspect, the neuro-pathology of this impairment may

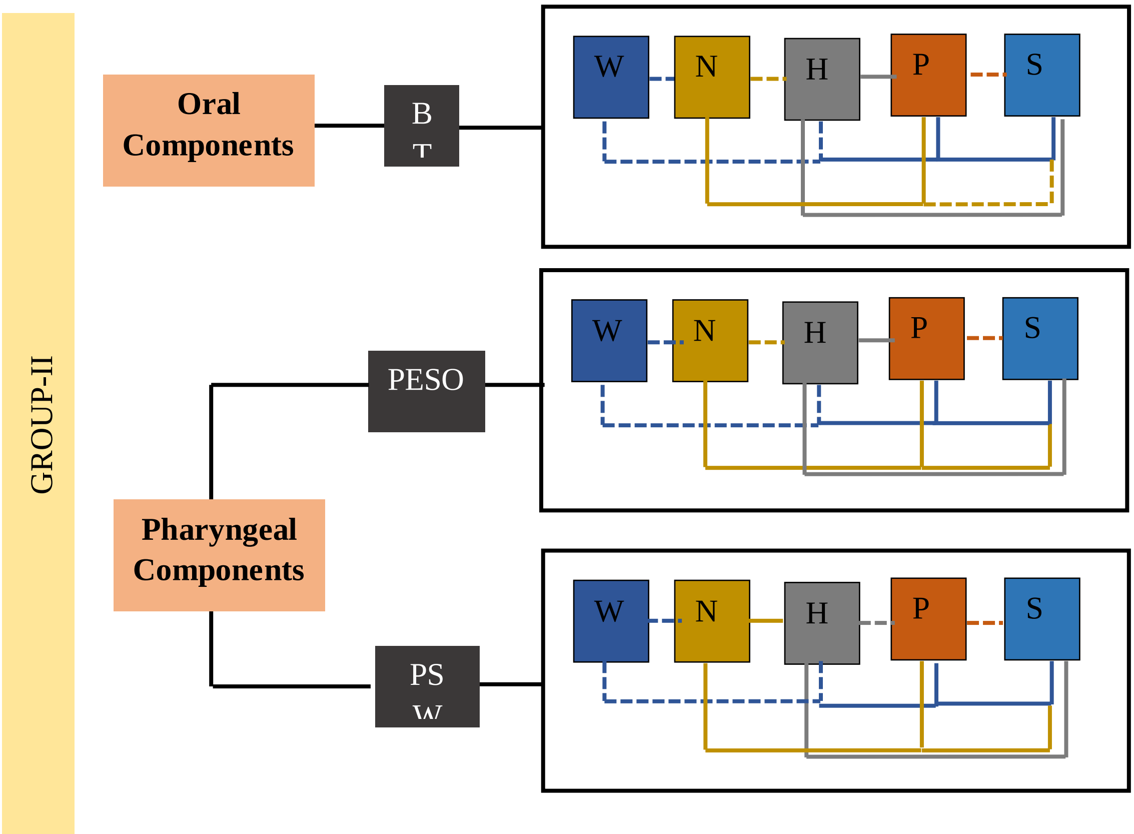

Figure 12. Comparison of component scores across bolus consistencies in Group II

be different from that of post stroke. Considering that MND is a lesion of central and peripheral neural network rather than the brain itself, sensory disintegration in swallow physiology may be due to the inefficient reception and relay of information to the relatively well functional brain centers. Lesser number of components that adapt to sensory information further suggests that the underlying neural network for most components of swallow is are impaired in the early and middle stages of the condition. The report of Fattori et.al. (2006) that solid consistencies are associated with increased esophageal inefficiency in persons with MND is not supported in the present study. From the results of the current study, esophageal clearance did not show significant differences in persons with MND across the five consistencies. A few studies published on MND dysphagia suggests that physiological differences exist across thin and thick consistencies (Briani et.al., 1998; Clave et.al., 2006). Further, the findings suggest that the protocol for VFSS evaluation in persons with MND may be shortened to three consistencies (Thin, Honey and Solid) rather than all the five consistencies included in MBSImp. This can shorter the duration of evaluation, radiation exposure, and overall time taken to complete the swallowing assessment. This further supports the need for pathology specific protocols for assessment of swallowing.

CHAPTER V

SUMMARY AND CONCLUSION

The aim of the present study was to profile the various physiological functions at oral, pharyngeal and esophageal phases of swallow as well as its adaptations to variations in bolus consistency in post stroke and persons diagnosed with MND with Video-Fluroscopic Swallowing Study conducted using the standard protocol of Modified Barium Swallow Impairment Profile (MBSImp^{TM}). Data was obtained from 27 individuals with stroke or MND (15 post stroke and 12 MND) selected using a strict inclusion criteria. The MBSImp component scores obtained were subjected to various statistical procedures for profiling and comparing across independent variables considered in the study. The major findings from these comparisons are as follows:

1. Impairment scores across bolus consistenciesin group I and group II
    a) The initiation of swallow reflex is the most affected swallowing physiology in both post stroke and MND population. The pharyngeal swallow reflex is most commonly initiated when the bolus head reaches the pyriform sinus indicating a delay in triggering this reflex.
    b) Soft Palate Elevation remained intact in both post stroke and MND during swallow of various bolus consistencies.
    c) Other oral components (Lip closure, Tongue Control) were impaired in post stroke but not in the participants with MND.
    d) Pharyngeal components were affected in both post stroke and MND population in varying degrees.
    e) Esophageal clearance was not impaired in post stroke but mildly impaired in MND

f) Dysphagia is primarily oro-pharyngeal in stroke but may include additional esophageal impairment in individuals with MND.

2. Comparison of MBSImp^{TM} component scores across group I and group II in each bolus consistency.

   a) There was no statistically significant difference in the impairment scores across stroke and MND population suggesting that these two different neuro-pathologies affect the swallowing system to the same degree during swallow of all bolus consistencies.

   b) Pharyngeal residue was the only component that showed significant difference across the conditions with higher pharyngeal residue in post stroke population during swallow of pudding consistency bolus.

   c) These findings suggest that oro-pharyngeal efficiency is more compromised in central lesion compared to the peripheral.

3. Comparison of MBSImp^{TM} component scores across bolus consistency in group I and group II.

   a) More number of components showed significant differences across bolus consistencies in post stroke compared to MND.

   b) In post stroke,

      - Lip closure showed differential involvement across bolus consistencies with greater impairment in thin compared to thick bolus. The overall efficiency of oral stage reduced with higher bolus consistency with greater oral residue in thick boluses. Lingual functions (Control and Movement) were not significantly different across bolus consistencies.
      - Soft palate elevation did not show differential performance across bolus consistencies. The pharyngeal driving force exerted by pharyngeal contraction

on the thick boluses was impaired resulting in weaker stripping for solid boluses.

- Airway decoupling functions (laryngeal elevation, laryngeal vestibular closure, anterior hyoid movements, epiglottic inversion) showed differential adaptations to sensory variations of the bolus.
- Upper esophageal opening function also showed differences across bolus consistencies probably due to its association with hyo-laryngeal elevation.
- The resultant efficiency of pharyngeal function, indicated by the pharyngeal residue, was higher in thick compared to thin boluses.

c) In MND

- Lingual movement was the only oral component that showed statistically significant differences across bolus consistencies. Bolus transport was more impaired in solid compared to thin boluses.
- It is the tongue movement rather than control that contributes to oral dysphagia in MND.
- Other oral stage components such as lip closure and oral residue were not significantly different across bolus consistencies.
- In the pharyngeal phase, pharyngeal stripping wave and upper esophageal functions had higher impairment scores in thick bolus consistency.

d) Both post stroke and MND swallowing physiology differentiated between thin, honey thick and thick bolus consistencies.

Clinical Implications:

The components of swallow assessment using the Modified Barium Swallow Assessment in persistent dysphagia are similar across post stroke and MND population. However, the current study implies that the protocol can be shortened for clinical use as the findings are significantly different across thin, honey-thick and thick bolus consistencies. The possibility for development of pathology specific VFSS assessment protocols needs to be explored for reducing the time, effort, resource consumption and overall efficiency of swallowing evaluations in persons with neurological dysphagia.

Future Directions:

1. The population considered in this study is heterogenous within each group. The various intrinsic variables of stroke and MND may be controlled and any variations in the observations could be studied.
2. Apart from consistency variations, it is important to know the interaction between other bolus characteristics such as volume, temperature, taste, texture and other sensory inputs obtained during natural feeding sessions. Incorporating the most influential sensory variables into assessment sessions can provide the dysphagia therapist with a comprehensive understanding of swallow function.
3. Pathology dependent VFSS assessment protocols could be developed without compromising the efficiency of such protocols in swallowing assessment. This could help in reducing the radiation exposure, and time consumed for evaluation and clinical decision.

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APPENDIX I

Oral Impairment

Component 1—Lip Closure

0 = No labial escape

1 = Interlabial escape; no progression to anterior lip

2 = Escape from interlabial space or lateral juncture; no extension beyond vermilion border

3 = Escape progressing to mid-chin

4 = Escape beyond mid-chin

Component 2—Tongue Control During Bolus Hold

0 = Cohesive bolus between tongue to palatal seal

1 = Escape to lateral buccal cavity/floor of mouth (FOM)

2 = Posterior escape of less than half of bolus

3 = Posterior escape of greater than half of bolus

Component 3—Bolus Preparation/Mastication

0 = Timely and efficient chewing and mashing

1 = Slow prolonged chewing/mashing with complete re-collection

2 = Disorganized chewing/mashing with solid pieces of bolus unchewed

3 = Minimal chewing/mashing with majority of bolus unchewed

Component 4 - Bolus Transport/Lingual Motion

0 = Brisk tongue motion

1 = Delayed initiation of tongue motion

2 = Slowed tongue motion

3 = Repetitive/disorganized tongue motion

4 = Minimal to no tongue motion

Component 5 – Oral Residue

0 = Complete oral clearance

1 = Trace residue lining oral structures

2 = Residue collection on oral structures

3 = Majority of bolus remaining

4 = Minimal to no clearance

Component 6—Initiation of Pharyngeal Swallow

0 = Bolus head at posterior angle of ramus (first hyoid excursion)

1 = Bolus head in valleculae

2 = Bolus head at posterior laryngeal surface of epiglottis

3 = Bolus head in pyriforms

4 = No visible initiation at any location

Pharyngeal impairment

Component 7—Soft Palate Elevation

0 = No bolus between soft palate (SP)/pharyngeal wall (PW)

1 = Trace column of contrast or air between SP and PW

2 = Escape to nasopharynx

3 = Escape to nasal cavity

4 = Escape to nostril with/without emission

Component 8—Laryngeal Elevation

0 = Complete superior movement of thyroid cartilage with complete approximation of arytenoids to epiglottic petiole

1 = Partial superior movement of thyroid cartilage/partial approximation of arytenoids to epiglottic petiole

2 = Minimal superior movement of thyroid cartilage with minimal approximation of arytenoids to epiglottic petiole

3 = No superior movement of thyroid cartilage

Component 9—Anterior Hyoid Excursion

0 = Complete anterior movement

1 = Partial anterior movement

2 = No anterior movement

Component 10–Epiglottic Movement

0 = Complete inversion

1 = Partial inversion

2 = No inversion

Component 11—Laryngeal Vestibular Closure – Height of Swallow

0 = Complete; no air/contrast in laryngeal vestibule

1 = Incomplete; narrow column air/contrast in laryngeal vestibule

2 = None; wide column air/contrast in laryngeal vestibule

Component 12—Pharyngeal Stripping Wave

0 = Present - complete

1 = Present - diminished

2 = Absent

Component 13—Pharyngeal Contraction (*A/P VIEW ONLY*)

0 = Complete

1 = Incomplete (Pseudodiverticulae)

2 = Unilateral Bulging

3 = Bilateral Bulging

Component 14—Pharyngoesophageal Segment Opening

0 = Complete distension and complete duration; no obstruction of flow

1 = Partial distension/partial duration; partial obstruction of flow

2 = Minimal distension/minimal duration; marked obstruction of flow

3 = No distension with total obstruction of flow

Component 15 — Tongue Base (TB) Retraction

0 = No contrast between TB and posterior pharyngeal wall (PW)

1 = Trace column of contrast or air between TB and PW

2 = Narrow column of contrast or air between TB and PW

3 = Wide column of contrast or air between TB and PW

4 = No visible posterior motion of TB

Component 16 — Pharyngeal Residue

0 = Complete pharyngeal clearance

1 = Trace residue within or on pharyngeal structures

2 = Collection of residue within or on pharyngeal structures

3 = Majority of contrast within or on pharyngeal structures

4 = Minimal to no pharyngeal clearance

Esophageal impairment

Component 17—Esophageal Clearance Upright Position

0 = Complete clearance; esophageal coating

1 = Esophageal retention

2 = Esophageal retention with retrograde flow below pharyngoesophageal segment (PES)

3 = Esophageal retention with retrograde flow through PES

4 = Minimal to no esophageal clearance