"You may never know what results come of your actions,
but if you do nothing, there will be no results."
Mahatma Gandhi

Acknowledgements

This work would not be complete without this section. Although the following sentences are written with deep feeling, no words could really express how thankful I am to all of tireless people who participated in this project.

First of all, to Therapist Adelaide Dias, who were responsible for this huge interest and passion I actually have for swallowing disorders, and for giving me the motivation I need to creation this research.

To Professor Miguel Coimbra in regard to all the guidance and help he gave to me with friendship, understanding and patience, as well as, to his encouragement words and sharing of knowledge and wisdom.

To Unidade de Saúde Local de Matosinhos – Hospital Pedro Hispano, mainly to Dr. Delfim Duarte, the director of ENT service, for authorizing the implementation of this research and for had provided the material necessary for its execution.

Specially thanks to Dr. Nuno Oliveira, doctor from ENT service, for his tireless availability, sympathy, patience and understanding. Without his precious collaboration this work would not be possible to do. Thank him also for its professionalism and sharing of knowledge.

I also express my gratitude to all volunteer participants, which made this happen and for having a fundamental contribution to the advancement of scientific research in this field of knowledge.

To my friend Guilherme and my cousin Claudia for their monitoring in English and for making me unlock my own English skills to develop this work.

To my work friends that help me a lot being my "guinea pigs" drinking water thickened, even though they had feel it was nasty. Thank them also for their real professional and emotional support and friendship, with getting tired.

To Rita, my housemate, who always believed in me and motivated me every day with strength and happiness. Thank her for her friendship and for making me laugh and to go on when nerves and fear seemed to take hold on me. Without her, this journey would have probably been difficult and less pleasant in the strenuous moments.

To all my friends for supported me with patience and friendship and for understanding my temporary unavailability in particular moments. To some of them, I also express my gratitude for their help in specific issues I found during this work.

To my family, especially my parents, for always believing in me and in what I do in personal and professional field. I am greatly honored for they giving me constantly love, support and dedication thorough my whole life. To them, I dedicate all this work.

I am completed blessed for having these incredible people in my life.
Thank you all!

Abstract

Despite of the uncertainties in the interpretation of swallowing sounds, Cervical Auscultation (CA) has been used as a complementary method in assessment of swallowing disorders.

The aims of this study is to describe the acoustic characteristics of swallowing sounds collected through an electronic stethoscope, using Cervical Auscultation method, in healthy adults, and to identify the anatomophysiological origin of sound components.

They were involved 20 subjects aged over 45 years old in good health. CA and Fibreoptic Endoscopic Evaluation of Swallowing (FEES) were performed simultaneously. Sounds were collected using an eletronic stethoscope into a computer device. For each subject it was tasted the swallowing of saliva, free gulp of thin liquid, 10ml of thin liquid, 5ml of pudding, 10ml of pudding and solid. A total of 116 swallowing sounds were analysed in terms of number of sound components and its order of appearing, duration of swallowing process and variation in frequency domain.

They were identified three sounds during swallowing in 59 records. Lub-Dub (LD) and Breath were the most observed sound component. Solid consistency presents the longest time, with a mean result of 15562+-2590 milliseconds, considering the total duration of anatomophysiological event, including Oral Transit Time (OTT). Without OTT, free gulp of thin liquid has the highest mean duration. The longest swallowing sound corresponds to 10ml of pudding. All subjects swallow saliva and 10ml of thin liquid in one gulp. The number of gulps increases with the raise of volume of the bolus. Considering the association between sounds and anatomophisyiological events, LD has the most significant result. In frequency range between 517 and 3617 Hz were observed the most significant difference between the consistencies. In a pilot study included in this thesis, there were found significant differences between duration of swallowing sounds from healthy and dysphagic individuals.

There is still no evidence that CA could be independently used. We can conclude that swallowing sounds contains acoustic characteristics that may allow reliable classification, but further researches are needed to achieve this goal.

Key words: Deglutition, Deglutition Disorders, Cervical Auscultation, Swallowing Sound, Adults.

Resumo

Apesar das incertezas existentes na interpretação dos sons da deglutição, a Auscultação Cervical (CA) tem vindo a ser usada como método complementar na avaliação das perturbações da deglutição.

Este estudo pretende descrever as características acústicas dos sons da deglutição recolhidos através de um estetoscópio eletrónico, utilizando o método da CA, em adultos saudáveis, bem como identificar a origem anatomofisiológica dos mesmos sons.

Participaram neste estudo 20 indivíduos com mais de 45 anos, em bom estado de saúde. A AC foi concretizada simultaneamente à realização da Videoendoscopia da Deglutição. Os sons foram recolhidos para um computador através de um estetoscópio eletrónico. Para cada participante foi testada a deglutição de saliva, deglutição em gole livre de liquido, 10ml de liquido fino, 5ml e 10 ml de pudim e sólido. Foram analisados 116 sons em relação ao número de constituintes identificados e ordem de aparecimento, duração do processo de deglutição e variação dos sons no domínio das frequências.

Foram identificados três sons da deglutição em 59 gravações. Lub-Dub (LD) e Breath foram os componentes sonoros mais observados. Considerando a duração total dos eventos anatomofisiológicos, a consistência sólido apresentou o tempo mais longo, com uma média de duração de 15562+-2590 milésimos de segundos, incluindo o Tempo de Trânsito Oral (TTO). Excluindo o TTO, a deglutição livre de líquido apresentou a duração média mais elevada. O som de deglutição mais comprido foi identificado na deglutição de 10ml de pudim. Todos os participantes deglutiram apenas num gole saliva e 10 ml de pudim. O número de goles aumenta com o aumento do volume de alimento. Considerando a associação entre o sons e os eventos anatomofisiológicos, LD foi o componente sonoro com resultado mais significativo. Relativamente às frequências, foram observadas diferenças mais significativas entre 517 e 3617 Hz. No estudo piloto incluído nesta teses, foram observadas diferenças significativas entre as durações medias dos sons da deglutição de indivíduos saudáveis e com disfagia.

Ainda não há evidencia de que a AC possa ser utilizada de forma independente. Conclui-se que os sons da deglutição contêm características acústicas possíveis de uma classificação confiável, no entanto, são necessários mais estudos para atingir esse objetivo.

Palavras-chave: Deglutição, Disfagia, Auscultação Cervical, Sons da deglutição, Adultos.

Preamble

Graduated in Speech and Language Pathology, since 2011, at Escola Superior de Tecnologias da Saúde do Porto (ESTSP), Politecnico do Porto, the author integrated a master's degree in Medical Informatics at Faculdade de Medicina da Universidade do Porto e Faculdade de Ciências da Universidade do Porto, in 2014.

The fact of working in a Continuing Care Unit Speech, evaluating, re-evaluating and treating individuals with swallowing disorders (resulting from stroke, brain injury or other neurologic conditions), created specific needs of knowledge in this field.

Due to difficulties felt in accessing objective exams to confirm the results of clinical assessment of swallowing disorders, stethoscope is the easier and accessible tool at that moment. However, CA is a hard skill to master depending on professional experience and it only has been used as a complementary method to reinforce an initial examination. Although some sounds could be clearly distinctive from each other, uncertainties still remain about the interpretation of the swallowing sounds. A digitally stethoscope could help in studying the acoustic characteristics of the swallowing sounds.

These issues after evolved to the need to know more about CA, by which the research process has been started and a huge interest to contribute to the study of swallowing sounds has grown up to make CA a stronger method, improving its use by health professional.

Table of Contents

List of figures

List of tables

List of abbreviations and acronyms

1B	First Burst
2B	Second burst
AC	Aucultação Cervical
BTS	Bolus Transport Signal
C	Click
CA	Cervical Auscultation
CN	Cranial Nerve
CSE	Clinical (bedside) Swallow Examinations
D	Deglutition of Younger
DA	Duration of apnea
DA	Deglutition
DS	Duration of swallowing
DSS	Duration of swallowing sounds
DSS-OTT	Duration of swallowing sounds without Oral Transit Time
ENT	Ear, Nose and Throat
FEES	Fiberoptic Endoscopic Evaluation of Swallowing
FFT	Fast Fourier Transform
I	Interval
LAS	Laryngeal Ascension Sound
LB	Lub-Dub
M	Men
M	Misc
msec	milliseconds
O	Older
OFF	Offset Time
ON	Onset Time
OTT	Oral Transit Time
PC	Preclicl
SC	Sound Component
SLP	Speech-Language Pathologist
T	Total duration
T/DA	Total duration/Duration of apnea

UES	Upper Esophageal Sphincter
VFSS	Videofluoroscopy Swallowing Study
W	Women
Y	Younger
PI	Peak Intensity
PF	Peak Freqency
SD	Standart Deviation

1. Introduction

This initial chapter is the first approach to this study, where will be exposed the research problem and its question, the objectives purposed to be studied and the contributions this work can bring not only to the scientific research but also to clinical practicing, mainly in Speech and Language Therapy field.

1.1. Research problem

Swallowing is a complex function of the body that requires the coordination of different structures of the oral cavity, pharynx, larynx and esophagus. It consists in the food passage from the oral cavity to stomach and involves important biological processes that ensure airway protection (Manuscript, 2009; Sarraf Shirazi & Moussavi, 2011; Valim et al., 2007)

However, some ambient and biological factors can disturb this coordination and swallowing becomes unsafe.

Dysphagia may cause a huge incapability, and in most extreme cases might lead to death, for being a risk factor of Aspiration Pneumonia, chronic lung disease, malnourishment or dehydration (Huang et al., 2014; Santamato et al., 2009; Valim et al., 2007).

It is important to make an early diagnosis of this pathology, mainly the signs of deglutition's pharyngeal phase, once that it is in this phase that it is possible to see all main mechanisms related with airway protection (Canongia & Alves, 2010; Sarraf Shirazi & Moussavi, 2011).

Currently, there are several ways to evaluate deglutition's capability that can be used in individuals that might present dysphagia.

Clinical (bedside) Swallow Examinations (CSE) is the most frequently used swallowing test in the first contact between patient and health professionals. Although it is ineffective in detecting silent aspiration, it is safe, simple and easily repeatable (Logeman, 1998).

Speech and Language Pathologists (SLP) usually use Cervical Auscultation (CA) to complete their dysphagia's clinical evaluation. This technique allows swallowing and breath sounds analysis by using a stethoscope (Borr et al., 2007; Moussavi, 2005).

To make an objective assessment there are exams using image as a resource to detect swallowing disturbs, such as silent aspiration phenomena. Videofluoroscopic Swallowing Study (VFSS) and Fiberoptic Endoscopic Evaluation of Swallowing (FEES) are considered the most effective methods to assess dysphagia (Ramsey, Smithard, & Kalra, 2003; Sarraf Shirazi et al. 2012).

Although less used in swallowing evaluation, there are other complementary exams such as Electromyography (Aboofazeli & Moussavi, 2006) and Pharyngeal Manometry (Shirazi & Moussavi, 2011). There also has been growing interest by the researchers in Sonoe Doppler (Santos et al, 2006; Soria & Furkim, 2016) and Accelerometry (Dudik et al., 2015; Lee et al., 2011) alternative methods of evaluating dysphagia.

In the last years, doctors and researchers are using new techniques based in sound analysis in order to develop alternative and specific techniques of swallowing evaluation (Balasubramanium & Bhat, 2012), such as CA. This method is based in sound analyzes from which it has to be decided if it corresponds to a dysphagia or a normal swallow. Therefore, it must contain objective information that allows classifying in an effective way.

CA has been used as a complementary method in assessment of swallowing disorders, but there are no protocols to conduit the procedures or any objective information about the signal meaning. Professionals interpret the sounds they heard according to their experience in this field, even though they unaware the true origin of the sound.

Despite the objective exams to evaluate swallowing skills, they not always are available on the health care institutions and could be expensive to the patient. CA has advantage of being less expensive, easier to carry and to use without drastically modifying the examination and the swallowing process. Therefore, CA might improve clinical practicing in swallowing disorders, if it could be used as an effective and safe method.

Swallowing sounds occur in milliseconds, requiring practice for a human ear to distinguish a normal from a pathological sound using a traditional stethoscope. A digitally stethoscope could help in studying the acoustic characteristics of the swallowing and make CA a stronger method, improving its use by health professional.

Many researches have been studying the characteristics of swallowing sounds in healthy and dysphagic people. However, there is still a disagreement between them regarding the duration of sounds, the number of sound components and their anatomophysiological origin.

1.2. Research question

The research question for this work is whether there is standardization in swallowing sounds in healthy people, allowing the use of Cervical Auscultation as a potential clinical method to detect swallowing disorders.

1.3. Objectives

The aims of this research is to study acoustic characteristics of swallowing sounds in healthy subjects collected through an electronic stethoscope, using CA method, and identify the anatomophysiological origin of sound components to try improve clinical assessment of swallowing disorders. More specifically, this study intends to:

- Describe swallowing sounds in healthy people according to volumes and consistencies of the bolus in terms of number of sound components and its order of appearing, duration of swallowing process and variation in frequency domain.

- Identify the origin of swallowing sounds, checking if all the anatomical and physiological events involved in the pharyngeal phase of swallowing, which are observable through FEES, have acoustic representation when collected by digital CA.
- Check if CA could be used as a secured method on swallowing assessment.

1.4. Thesis structure

The thesis is organised in fifteen chapters:

- Chapter one: corresponds to this first approach to this work.
- Chapter two: defined a normal Swallowing and describes the main concepts about the anatomy and physiology of wallowing.
- Chapter three: defines dysphagia, presenting classifications done according to its cause or changes in deglutition phases, and classifications of disorders in pharyngeal dysphagia of neurological.
- Chapter four: indicates the prevalence of stroke and its relation with dysphagia, as well as, their impact on quality of life.
- Chapter five: presents swallowing assessment methods.
- Chapter six: describes the role of Speech-Language Pathologist in swallowing disorders.
- Chapter seven: describes some main concepts related with acoustic analysis of sounds.
- Chapter eight: presents results from previous studies in regard to swallowing sound and cervical auscultation using a digital stethoscope.
- Chapter nine: presents the study design and implementation.
- Chapter ten: reports the results of the implementation.
- Chapter eleven: analyse the results, comparing them with others that were found in state of art, and describes some limitations of this work.
- Chapter twelve: presents the main findings and some recommendations.
- Chapter thirteen: purposes to a future work.
- Chapter fourteen: presents references used thorough this work.
- Chapter fifteen: presents the appendix.

2. Normal Swallowing

Swallowing is a complex behaviour with reflex and voluntary actions, involving different structures. An healthy adult swallows approximately 600 times a day, about 35 times per hour while awake and 6 times per hour while sleeping (Manuscript, 2009).

Health professional can only make a corrected swallowing evaluation if they have knowledge of all involved structures and about the physiology of this process. It is important to get the right information about the patients so they can posteriorly plan individuals' rehabilitation in an adjusted and individualized way.

2.1. Anatomy and Physiology of Swallowing

Different anatomical structures are involved in swallowing events. Bone structures with a distinct participation in this process are maxilla, mandible, cervical spine and hyoid bone. From involved articulations, stands out larynx cartilages: 3 unpaired cartilages (cricoids, thyroid, epiglottis) and 3 pairs of smaller cartilages (arytenoids, corniculate, cuneiform) (Jotz et al., 2009; Leslie et al., 2007; Manuscript, 2009).

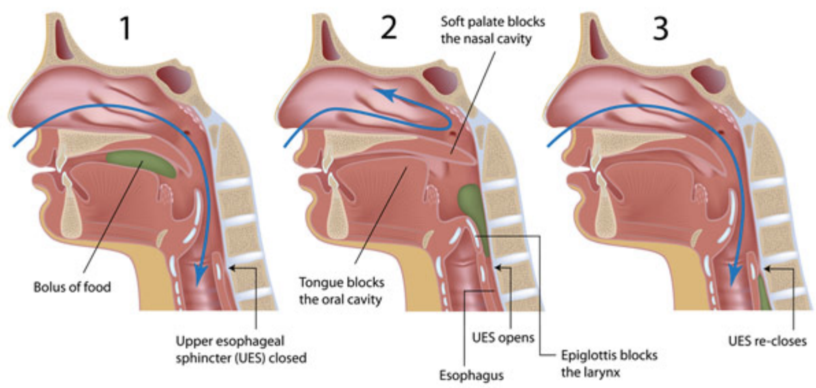
Muscle structures are mentioned as tongue and suprahyoid muscles, such as digastric, stylohyoid and infrahyoid muscle. Tongue has both oral and pharyngeal surfaces. Faucial pillars separate oral cavity from pharynx, where there is a tier of constrictors muscles that are originated in hyoid bone and cranium. Cricopharyngeus muscles are connected to the sides of cricoids cartilage and it closes Upper Esophageal Sphincter (UES), compressing it against posterior part of cricoids cartilage. Between tongue's pharyngeal surface and epiglottis there are the valleculae. In larynx there are the true and the false vocal folds. Adjacent to the larynx, there are two spaces named pyriform recesses (Jotz et al., 2009; Leslie et al., 2007; Manuscript, 2009).

Deglutition demands neuromotor control with participation of cerebral cortex, cerebral trunk and six pairs of Cranial Nerves (CN) that determine sensory and motor impulses, controlling approximately 31 muscles. Involving CN, they all contain both sensory and motor fibers, with exception of CN XII that just contains motor fibers

CN V (Trigeminal) has three divisions (the ophthalmic, maxillary and mandibular nerves). It is responsible for sensation to nasopharynx mucosa, soft palate, hard palate, gums, upper and lower teeth, lips, lower eyelid, sensitivity of the anterior 2/3 of tongue (except sensory taste receptors), cheeks mucosa, floor of the mouth and Temporomandibular Joint. Controls the muscles of mastication (masseter, temporal, pterygoid, mylohyoid, and digastric) and tensor muscle of soft palate. CN VII (Facial) controls the sensation in oropharynx and taste to anterior 2/3 of tongue. Controls facial muscles, stylohyoid, platysma and posterior belly of digastric. CN IX (Glossopharyngeal) is the nerve of ordinary sensation (pressure, touch, temperature and pain) to the pharynx, faucial pillars and palatine tonsil and controls the taste of posterior part of the tongue. It controls stylopharingeus that is involved in pharynx movimentes. CN X (Vagus) is responsible for movements of pharynx muscles (except stylopharingeus) muscle of soft palate (except tensor muscle) and larynx movements that are necessary for airway protection. It is important for sensation to oropharynx, larynx, epiglottis and valleculae mucosa. CN XII (Hypoglossal) controls all tongue movements (Manuscript, 2009; Rainbow, 2001).

2.2. Stages of swallowing

A normal swallowing is generally divided into three phases known as Oral, Pharyngeal and Esophageal (Aboofazeli & Moussavi, 2006; Palmer & Hilamae, 2003). The first phase has its beginning with food entry in mouth. When bolus is ready, tongue exerts pressure against pallet, pushing it towards oropharynx, and Pharyngeal phase starts. This process is now automatic; food stimulates sensory receptors, which trigger the swallowing reflex. In this phase, bolus is transported from oropharynx to pharynx, reaches the epiglottis and then larynx goes up. Esophageal phase starts with bolus passage to esophagus and then food is carried into the stomach by its peristaltic contractions (Canongia & Alves, 2010; Jotz et al., 2009; Sarraf Shirazi & Moussavi, 2011). Figure 1 shows a representation of



swallowing phases.

Figure 1: Representation of three phases of the normal swallowing: (1) Oral phase; (2) Pharyngeal phase; (3)Esophageal phase. Adapt. (Humbert, Christopherson, & Lokhande, 2015)

Some authors consider four swallowing stages, dividing Oral Phase in Oral Preparatory Stage and Oral Propulsive Stage. Oral Preparatory Stage corresponds to the moment when bolus is introduced in mouth and starts bolus preparation with the adequate consistency that allows its passage towards stomach. Oral Propulsive Stage has its beginning with bolus transfer from anterior oral cavity to oropharynx propelled by the tongue movements (Hammoudi et al., 2014; Jotz et al., 2009; Hilamae & Palmer, 1999; Manuscript, 2009; Palmer et al., 1992)

However, it is known that there are differences in bolus manipulation, according to introduced food in mouth, and Process Model of Feeding was established to describe the mechanism of eating and swallowing of solid food. All swallowing stages will be explained in detail according to this model (Manuscript, 2009).

Pharyngeal phase involves the most important and complex anatomical and physiological events related to airway protection, which occur rapidly sequential manner. Soft palate elevates against lateral and posterior pharyngeal walls, closing nasopharynx, and then soft palate rises to prevent nasal regurgitation. Tongue base moves back pushing bolus against pharyngeal walls. Pharyngeal constrictor muscles (upper, medium and lower) are activated to transport bolus towards the Pharynx by pharyngeal peristaltic contraction (Manuscript, 2009).

In this stage it is possible to verify the mechanisms of airway protection, which prevent episodes of foreign body aspiration in the trachea before or during swallowing. The vocal folds close to seal the glottis (space between the vocal folds) and the arytenoids tilt forward to contact the epiglottic creating a rapid moment of apnea. Hyoid bone and larynx are pulled upward and forward by contraction of suprahyoid and thyrohyoid muscle. Bolus moves into esophagus after UES is opened (Manuscript, 2009) and then the Esophageal stage begins.

In sum, swallowing is one of the most complex mechanisms that occur in human body (Sarraf Shirazi et al., 2012; Yadollahi & Moussavi, 2007). During all this process, it is possible to observe a sequence of phenomena that they only last milliseconds, which duration and coordination are crucial for a normal and safe swallowing. Any delay or change in this sequence might cause a Oropharyngeal Aspiration and thus dysphagia (Aboofazeli & Moussavi, 2006; Hammoudi et al., 2014; Moussavi, 2005; Sarraf Shirazi & Moussavi, 2011; Valim et al., 2007)

3. Dysphagia

Dysphagia refers to a symptom related with changes that occur during deglutition's phase that might block or hamper a safe, efficient and comfortable ingestion of food. It may occur in any age group, from new-borns till seniors, due to many different causes (Jotz et al., 2009).

In adults, the most common cause of dysphagia are neurological problems such as Stoke, Parkinson, Alzheimer, Severe Myasthenia, Amyotrophic Lateral Sclerosis, Traumatic Brain Injury and Cerebral Palsy. Dysphagia is also associated to aging process, neck and head cancer, brain tumors and gastroenterological disorders (Escoura, 1998; Jotz et al., 2009).

Classification of dysphagia can be done according to its cause or the phase of swallowing where disorder happens.

3.1. Classification of dysphagia according to the cause

- Mechanical Dysphagia: normally associated to structural changes caused by head and neck cancer, traumas, infections, among others (Jotz et al., 2009).
- Neurogenic Dysphagia: it is related to the central or peripheral nervous system (Jotz et al., 2009).

3.2. Classification of dysphagia considering changes in deglutition phases

- Oral Dysphagia: when there is commitment in the occurred events of Oral Preparatory phase and Oral Propulsive phase. It might be present in cases, such as Oral-Motor Apraxia, Tongue unilateral paralysis and also in maladjusted dental prosthesis (Jotz et al., 2009).
- Pharyngeal Dysphagia: when there is commitment in Pharyngeal phase in one or more phenomena present, such as in cases like pharynx and larynx paralysis or partial laryngectomy (Jotz et al., 2009).
- Oropharyngeal Dysphagia: due to its narrow relation between occurred events

in Oral Propulsive phase and Pharyngeal phase, in most part of cases it is possible to observe changes of both phases, specially in neurological diseases (Jotz et al., 2009).

- Esophageal Dysphagia: it occurs when there are mechanical changes and/or dysmotility (e.g. Achalasia). Tumors in the region of the lower esophageal sphincter or gastric cardia can give rise to "pseudo-achalasia". The diagnosis of this condition is made after medical evaluation and objective tests such as Esophageal Biopsies (Kuo et al., 2012). In contrast with what happens on dysphagia of other types, SLP cannot intervene in Esophageal.

3.3. Classification of disorders in Pharyngeal Dysphagia of neurological

- Light Dysphagia: when bolus control and transport is delayed and slow. In these cases, normally are loss of food through lips, tongue's incoordination, c, absence of cough, absence of significant changes in larynx mobility, absence of change of vocal quality after deglutition and negative CA (Escoura, 1998).
- Mild or Moderate Dysphagia: when bolus control and transport is delayed and slow, with signs of Oropharyngeal Aspiration. In general it is possible to observe los of food through lips, tongue's incoordination, when bolus control and transport is delayed and slow, absence of cough, presence of cough before, during or after deglutition, larynx mobility decrease, vocal quality changes after deglutition and CA sometimes modified (Escoura, 1998).
- Severe Dysphagia: when there is a considerable presence of Oropharyngeal Aspiration and absence or fail in bolus complete deglutition. It is possible to observe a delay or absence in deglutition's reflex, Larynx mobility decrease, absence of cough, presence of cough during or after deglutition, vocal quality changes after deglutition, a evident breath change, modified CA and incomplete deglutition (Escoura, 1998).

4. Stroke, swallowing disorders and their impact on quality of life

Stroke is still one of the main mortality causes in Europe (Carvalhido & Pontes, 2009; CIES Observatório das Desigualdades, 2012; Sousa-Uva & Dias, n.d.).

In Portugal, there isn't yet much information about this issue. According to literature's most referenced Community based study, involving people over 50 years old, from Coimbra's county, it is estimated that Stroke prevalence in Portugal might be about 8% (male gender: 10,2%, female gender: 6,6%) (Carvalhido & Pontes, 2009). A more recent study, made in 2013, suggests that Stroke gross prevalence for the resident people in mainland Portugal is 1.9% (Sousa-Uva & Dias, n.d.).

The highest prevalence of stroke was observed in Male gender people with ages between 65 and 74 years old (Sousa-Uva & Dias, n.d.). In the US, studies showed that 34% of people hospitalized for stroke were younger than 65 years (Hall, Levant, & DeFrances, 2012).

Stroke is considered the main cause of dependence and inability of Portuguese population, despite all increasing positive developments in prevention and rehabilitation areas (Carvalhido & Pontes, 2009)

Mortality rate caused by cardiovascular diseases has decreased between 2007 and 2011, from 79,9 deaths per 100 000 inhabitants to 61,9 (Direção-Geral da Saúde, 2013). With all advances in health area, it is possible to verify that there is a growing number of people that survived to this condition, being more frequent the presence of sequelae in these people.

All effects caused by a Stroke are unpredictable and diverse. Brain is an extremely complex organ that controls several parts of human body, and all consequences vary according to brain's affected region. It might appear some changes that can be physical, emotional or behavioural and communication or speech (American Heart Association, 2012). Swallowing disorders are associated to Stroke (Santamato et al., 2009).

Dysphagia is a condition that is present in most individuals with stroke, especially in the acute stage (González-Fernández, Ottenstein, Atanelov, & Christian, 2013), and it is one of the most common causes of morbidity (Falsetti et al., 2009). In some situations patients recover spontaneously and virtually without sequelae. Other ones maintain long-term difficulties that put them at risk of malnutrition, dehydration and develop pneumonia (González-Fernández et al., 2013; Falsetti et al., 2009) and in extreme cases, lead to death (Huang et al., 2014). There is a high incidence of aspiration pneumonia associated with dysphagia after stroke. It may occur in 43% to 50% of cases during the first year, with a mortality rate of about 45%. It is also associated with recurrent and prolonged hospitalization (Smithard et al., 2007).

In more serious cases, oral feeding is no longer possible and it is necessary to find alternative forms of nutrition and hydration. In on of the articles found it was mentioned that 80% of individuals with long-term dysphagia require alternative means of enteral feeding (Broadley et al., 2003). These disabilities can significantly impact the quality of life of these people (González-Fernández et al., 2013; Huang et al., 2014; Falsetti et al., 2009; Singh, 2006; Smithard et al., 2007).

It is a difficult task to assess quality of life because it depends on a subjective assessment that involves parameters related to personal, social, professional and emotional aspects of a person's life (Jotz et al., 2009). WHO defines Quality of Life "as individuals perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (Group, 1998).

Restrictions and swallowing difficulties experienced by these individuals in their daily routines can lead to feelings of frustration, discouragement, shame and embarrassment especially when they are in front of their family, friends and colleagues. These feelings can make them to want to have a meal alone and avoid public places (Jotz et al., 2009). Often there are sensorial changes, such as the change in the sense of taste, and less pleasure in eating.

Ekberg et al., 2002, notes that only 45% of individuals with dysphagia have pleasure in eating, 41% experience anxiety and panic during meals and that more than 1/3 of the individuals avoid eating because of swallowing difficulties (Ekberg et al, 2002).

The evaluation of swallowing disorders is an important process in monitoring of this people, without forgetting the study of quality of life, although it will not be a subject in this study.

5. Swallowing Assessment

Prior to the completion of the evaluation process, the health professional should collect all necessary and available information about the person who will observe, namely its ability to respond to anamnesis issues. The anamnesis is the first step in this process, enabling the detection of signals that may be associated with changes in swallowing and in the perception of expectations of the person and/or caregivers to the feed. Anamnesis is also important because it is the first contact between the healthcare professional and the person with dysphagia, being at this stage that starts the therapeutic ratio.

Evaluation's decision depends on the underlying pathology of the person, the data collected during anamnesis, and the all factors involved in the intervention context.

Currently, the standard of dysphagia assessment begins with CSE to observation of signs and symptoms (Dudik et al., 2015). This evaluation is very simple, easily reproducible, doesn't have any risk to the person examined and allows to define disturbances on oral phase and to analyse aspiration risk signs. However, it is not effective in silent aspiration's detection, because it doesn't allow direct observation of pharyngeal phase (Ramsey et al., 2003; Santamato et al., 2009).

Over time, they have been developing studies that investigates the reliability and validity of these two forms of assessment (Bergstrom et al., 2013).

Screening test indicates the probability of an individual having dysphagia and the need to be monitored by a SLP for a complete evaluation. It does not define the severity nor the nature of dysphagia and can not be used to plan the intervention (Bergstrom et al., 2013).

CSE may actually occur as the first dysphagia assessment (with no screening test taking place) or may occur after a simple screening test. The purpose of the CSE is to determine the individual's baseline, realizing their real skills, may using a swallowing evaluation protocols, and to plan intervention in dysphagia (Carnaby-Mann & Lenius, 2008; Cichero & Murdoch, 2006; Luker et al., 2010; Bergstrom et al., 2013).

5.1. Clinical evaluation of swallowing

Clinical examination is made perceptually, according to the knowledge of the observer and his professional experience. Prior to food swallowing test, must be observed all the structures involved in stomatognathic functions. It begins by evaluating the oral sensory-motor system, seeking to collect information in regard to the overall look, symmetry and posture, extra sensibility and intra-oral, tone and mobility of oral and laryngeal structures, as well as oral reflex (pathological and normal). The professional ought to conduct a thorough neurological examination of the cranial nerves, through specific orders to overall assessment of their duties. The evaluation of speech (voice and joint) is also required to complete the process (Donovan et al., 2013).

If the individual has conditions to eat certain food or liquid, the assessment continues using different consistencies, selected according to the characteristics of the person identified in previous procedures (Canongia & Alves, 2010). This type of evaluation is often called functional assessment. After the consistency test being defined, and respective order, must be aware of the clinical signs of alternations in the biomechanics of swallowing according to Logeman (1998) (Table 1).

Table 1: Description of Clinical Signals of Changes in Swallowing Biomechanic

Signs	Description
▪ Food or liquid leaking from the mouth	Loss of food through lips due to oral sensibility reduced or labial strength decreased.
▪ Extra effort or time needed to chew or swallowing	More or less time need from the bolus catchment to movement to the beginning of hyolaryngeal complex.
▪ Nasal regurgitation	Food's reflux to nasal cavity showing hypofunction of soft palate.
▪ Multiple gulps	The increasing number of gulps that are needed to complete food's cleanliness, as a dysphagia indicator.
▪ Laryngeal elevation changes	Difficulty in anterior and superior larynx movements during deglutition, which indicates an increasing of aspiration's risk due to limitation on protection of airway.
▪ Food or liquid stuck in the pharynx or larynx	Food leavings observation on Epiglottic vallecula and/or vocal folds before (premature leakage of foods) or after deglutition.
▪ Apnea's deglutition time changed	Effective time between food entry in pharynx and its passage to esophagus, in which shall occur an ininterrupt apnea.
▪ Oxygen saturation changed	Pulse oxymetre's usage to detect Oropharyngeal Aspiration, basing in the chance that food's aspiration would cause bronchospasm reflex causing oxygen's saturation fall.
▪ Vocal quality changed	Aims identify the presence or absence of wet voice after food or liquid swallowing by way of comparison pre and post swallows.
▪ Airway protection changed	- Cough: it is a reflex answer of brainstem that protects airway against foreign bodies entrance. - Choking: airway obstruction due to foreign bodies - Dyspnoea: feeling like cannot breathe sufficiently
▪ Other clinical signs	Cyanosis, bronchospasm, changes in vital signs.

To complete the functional assessment of swallowing, SLP must resort to CA (before, during and after the swallowing process). Pulse Oxymetry can also be used to complete evaluation of dysphagia.

SLP can guide their evaluation through informal or formal protocols. There are two types of instruments: those that assess the functional swallowing skills and other assessing how swallowing influences the quality of life of a person. The existence of several rating scales proofs that there is no optimal method that can be applied equally to all people. Some scales were developed and validated for use in specific circumstances such as in cancer pathologies of the head and neck. Thus, it is important to analyse all the factors in deciding the most appropriate protocol (Vinidh Paleri & Bradley, 2012).

5.1.1. Selecting consistencies and volumes of the bolus

There are different classifications to define the consistencies of food. Most authors consider that the consistency can range from thin, nectar-thick and honey-thick liquid, semi-solid, soft solid consistence and hard solid.

Thin liquids (such as water) rapidly lose its cohesion. Thus, if the person has a serious deterioration of swallowing, the risk of penetration and aspiration increases considerably. In these situations the assessment can be carried out using a slightly thicker consistency as the nectar-thick and honey-thick (Cichero & Murdoch, 2006).

All consistencies are ingested, swallowed and handled in different ways. The volume of food also influences how we control the cake in the mouth and the way we swallow it. Volumes 5 and 10 ml are considered the most appropriate for use in functional swallowing assessment by providing more accurate information to identify the tell-tale signs of laryngeal penetration and tracheal aspiration, and to facilitate the interpretation and preparation of the intervention process (Logeman, 1998). In most studies found in regard to this subject the volumes of 5 and 10 ml are the selections of researchers, making measurements with appropriate spoons or syringes.

5.2. Cervical Auscultation

This technique stands out for being a non-invasive and simple manipulation procedure in individuals that are seriously affected (Borr et al., 2007). This technique complements clinical evaluation, it gives additional information about pharyngeal phase with no significant influence in the process of swallowing.

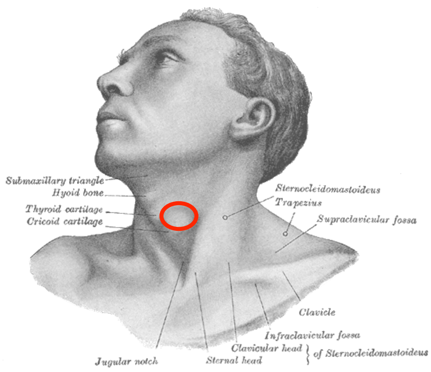


Figure 2: Placement of the stethoscope for cervical auscultation. The red circle corresponds to the placement of the stethoscope. Adapt. (Gray, 1985)

You can hear the sounds of breathing and swallowing through a stethoscope, placed on the lateral side of the neck onto the lateral border of larynx and trachea (posteroinferior border of the cricoid cartilage) (Takahashi et al., 1994).

In 1992, first suggestion were made about the existence of three physiological causes of the sounds of swallowing: the first sound corresponds to the elevation of the larynx and bolus flow through the pharynx; the second corresponds to the passage of the cake by the hypopharynx and the movement of the cricopharyngeal sphincter; the last sound is associated with the downward movement of the larynx, after swallowing (Cichero & Murdoch, 2006).

Over the years, there are still studies to be carried to analyze these phenomena, and there is still controversy regarding the source of sounds of swallowing. More recent studies point to the existence of more than three sounds of swallowing.

The majority of studies conclude that the AC can not be used as an isolated method in tracheal aspiration detection, but add that it should not be excluded from the clinical evaluation (Borr et al., 2007; Leslie et al 2004; Santamato et al. 2009; Stroud et al., 2002)

When you hold the acoustic analysis of sounds, consider that the results suggest lack of parameters used to investigate the temporal structure of swallowing sounds. Reinforce the idea that the values are not suitable for use as guidance in defining a diagnosis of dysphagia with particular risk of aspiration and penetration (Borr et al., 2007; Santamato et al., 2009).

Yet there is little evidence regarding the correspondence between the sounds of swallowing and physiological events of the pharyngeal phase which makes the standard changes detection (normal or pathological) more difficult, so you cannot replace the objective tests.

However, CA made through this way still remains as a subjective method (Santamato et al., 2009) because it depends on appraiser's characteristics and its clinical experience (Rainbow, 2001).

5.2.1. Traditional stethoscope versus digital stethoscope

These days there are two types of stethoscopes on the market that can be used by health professionals: the traditional acoustic and electronic (amplifying and digitizing) stethoscopes (Alaska Native Tribal Health Consortium, 2013; Cruz-Cunha et al. 2016; Leng et al., 2015)

Traditional acoustic stethoscope, created in 1816 by French physician Renne Laennec, is a device that allows listen sounds coming from inside the body. Initially it was made up of a wooden tube and was monaural, meaning that only you could hear was the sound of a single ear. In 1851 Arthur Leard invented the binaural stethoscope with characteristics similar to that currently used in clinical practice. The information provided by acoustic stethoscope is due to three distinct components (Chest Piece, tubing and ear pieces) each with a specific function (Cruz-Cunha et al., 2016; Leng et al., 2015).

The acoustic stethoscope allows the transmission of the sound that is collected from the chest piece through the tubing to the examiner's ear (Cruz-Cunha et al., 2016; Leng et al., 2015).

The chest piece is usually made up of two parts that have to be in direct contact with the person examined to be able to extract sound, these are: the bell (hollow cup) and the diaphragm (disc). The examiner hears the sound that results from converting pressure waves transmitted by the human body (Cruz-Cunha et al., 2016; Leng et al., 2015).

Stethoscope tubing can be defined as a means of sound propagation. It consists of a hollow tube with air that allows the passage of sound energy picked up by the chest piece to the examiner's ear (Cruz-Cunha et al., 2016; Leng et al., 2015).

Ear Pieces closes the circuit propagation of the collected sound. Any change in this process, such as rupture of any of the components can result in decreased sound quality, or completely prevent its transmission (Cruz-Cunha et al., 2016; Leng et al., 2015).

Electronic stethoscope, created by Albert Abrams, amplifies the sound of the human body through advanced technology, overcoming the noise levels that are normally associated with sound recorded by traditional stethoscopes. These devices convert acoustic sound waves through the chest piece obtained by electronic signals propagating in well-defined circuits to process a sound optimization on different frequencies (Alaska Native Tribal Health Consortium, 2013; Cruz-Cunha et al., 2016; Leng et al., 2015)

Electronic stethoscope has also the function of scanning, coding and decoding beep, managing to reduce ambient noise and eliminate other type of contamination of the original sound. The collected sound generally can be recorded to an external device such as a computer or tablet, to be subsequently manipulated (for example, signal processing). This allows the health professional access to this information every time they consider necessary for their clinical practice to confirm diagnoses or control medical conditions (Alaska Native Tribal Health Consortium, 2013; Cruz-Cunha et al., 2016; Leng et al., 2015).

It is understood that the above characteristics are presented as the primary advantages of electronic stethoscopes compared to traditional. As disadvantages it is mentioned that they are generally heavier and more difficult to transport. Furthermore they require batteries to operate properly and are more expensive than the traditional ones. They can also suffer interference from mobile phones or other devices that emit electronic signals (Alaska Native Tribal Health Consortium, 2013; Cruz-Cunha et al., 2016; Leng et al., 2015).

5.3. Pulse Oxymetry

Pulse Oximetry is a method of assessment using a device (pulse oximeter) that is placed on the finger and, through infrared light, measures blood oxygen saturation of the blood. Prior to the evaluation of swallowing are measured baseline values. During the Feeding of the test consistency, the values observed are the oxygen saturation of the blood and compared with the initial values. Variations in saturation may be indicative of aspiration or penetration without clearing the bolus (Rainbow, 2001; Ramsey et al., 2010).

More recent studies are inconclusive regarding the association of these phenomena. Some researchers find relationship but with the wide range of sensitivity and specificity values on comparison with VFSS or FEES (Ramsey et al., 2010).

Although uncertainties remain regarding its effectiveness in detecting aspiration and penetration, this method continues to be part of most protocols established by SLP in the evaluation of swallowing disorders.

In order to objectify the results of the functional assessment of swallowing, especially in inconclusive clinical examinations, supplementary diagnostic tests may be performed in order to identify the actual skills and limits of swallowing.

5.4. Objective assessment of swallowing

According to The American Speech-Language-Hearing Association (ASHA) a clinical-instrumental correct evaluation of swallowing must be such as organic and functional alterations of the structural involved and identify the level of effectiveness of swallowing in different phases. It should also enable the observation of the mechanisms involved in the protection of the lower airways and co-ordination between breathing and swallowing, as well as allow the detection and, if possible, quantify any penetration of the bolus in the tracheal-bronchial passage (Nacci et al., 2008; American Speech-Language-Hearing Association, n.d.)

Currently the two most used objective evaluation methods of swallowing are VFSS and FEES. Both are considered the most effective methods for evaluation of dysphagia (Ramsey et al., 2003; Sarraf Shirazi et al., 2012), using the image to observe the anatomical and physiological phenomena that occur during the process of swallowing.

5.4.1. Videofluoroscopy Swallowing Study

VFSS is a radiological exam that uses modified barium during swallowing. Allows to evaluate the anatomy and physiology of swallowing, and monitor the traffic of the bolus in real time, evidenced all these amendments in case of dysphagia, including disturbed structures and pathological phenomena (such as silent aspiration) (Rainbow, 2001).

It is considered the gold standard, although it presents some disadvantages, due to its not portable, complex and slow process and imply that people are exposed to radiation (Ramsey et al., 2003), which gets harder to make a periodic revaluations and compromise intervention's effectiveness.

5.4.2. Fibre-Optic Endoscopic Evaluation of Swallowing Safety

FEES is often the first choice when it comes to choosing the objective method for the study of swallowing disorders (American Speech-Language-Hearing Association, 2004).

Using a nasendoscope can functionally evaluate the pharyngeal stage of swallowing. The test involves inserting a flexible endoscope through the nose, getting positioned with the tip slightly below the uvula and above the vocal cords. Some people need local anesthesia during the exam because they show greater discomfort associated with the endoscope (Rainbow, 2001).

During this examination are requested speech tasks as well as vocalizations to assess the anatomy and physiology of the velum, oropharynx, hypopharynx and larynx. The evaluation of swallowing is performed using different food types (according to the pre-established objectives) containing food coloring. This dye helps differentiate more easily foods secretions, structures and mucous in the oropharynx and larynx (Working). During this examination it is still possible to test maneuvers and swallowing strategies required for effective and safe (American Speech-Language-Hearing Association, n.d.).

The conduct of the examination and analysis of the results from the SLP requires advanced knowledge and specific on this area. According to American Speech-Language-Hearing Association (2004), SLP should be able to: determine the appropriate evaluation protocol; make quick and assertive decisions during the examination; have knowledge about the anatomy and physiology of the larynx; observe secretions; quickly assess swallowing food and liquid; select therapeutic maneuvers and interventions to Improve the swallow (American Speech-Language-Hearing Association, n.d.)

FEES can be performed during hospitalization at the bedside or in an outpatients department, being advantageous for individuals who have some sort of limitation or restriction that prevents them from moving on. Also it can be recorded in video if needed, it is a safe method and tolerated. It can be done with periodicity in order to control patient's evolution (Rainbow, 2001).

However, it has some disadvantages such as the fact that only allow access to the pharyngeal phase of swallowing. It is also dependent on qualified health professional and specialized also equipment. Besides that, it provides little information about pharyngeal and esophageal phases (Ramsey et al., 2003) and presents swallowing *whiteout*, when the swallowing reflex starts and the endoscope is in contact with the base of the tongue, with the epiglottis and the bolus itself, losing image (American Speech-Language-Hearing Association, 2004; Nacci et al., 2008).

5.5. Factors that influence a normal swallowing

Eating and drinking are basic needs for human being. For the majority, these actions assume big importance for its social character, considering the number of meals in someone else's company, happening often in public places. Appetite, food presentation, the atmosphere, local hygiene and comfort of, social context, person's state of mind and their life experiences may influence the way how we eat or drink (Rainbow, 2001).

Deglutition's physiology may be influenced by the following factors: posture, self-feeding, cognitive influences, bolus size, bolus viscosity, disuse-dysfunction and normal ageing. Therefore, it is necessary to take into account all these factors during evaluation process and dysphagia's intervention (Rainbow, 2001).

6. Role of Speech-Language Pathologist in swallowing disorders

According to American Speech-Language-Hearing Association (n.d.), SPL play a primary role in the evaluation and treatment of swallowing and feeding disorders in infants, children, and adults.

This professional have knowledge of anatomy, physiology, and functional aspects of the upper aerodigestive tract (including oral, pharyngeal and cervical esophageal anatomic regions), that are involved in swallowing process and speech. He knows about underlying medical and behavioral etiologies of swallowing and feeding disorders too. Considering cognition, language, and behavioural skills could be affected in these patients, SLP could be more efficient diagnosis and management of swallowing, hence he is expert in communication disorders (Arvedson et al., 2015).

The assessment of swallowing disorders is a crucial moment for developing management strategies. First of all, SLP needs to take a careful history of medical conditions and symptom of the patient. Then, he has to examine the strength and movement of the muscles that are involved in swallowing process. Following a correct procedure, he has to observe the patient feeding looking to posture, behavior, and oral movements during eating and drinking.

The treatment is depending on the cause, symptoms, and type of swallowing problem SLP had detected. Usually, exercises to improve muscle movement are needed. SLP can also give strategies to help the individual to swallow safety more effectively and to select specific consistencies of food and liquid textures most appropriated to the patient. Family and caregivers are included in intervention too. They can make question and expose the doubts as well as to share strategies and receive recommendations to follow out of the therapy context (American Speech-Language-Hearing Association, n.d.)

In fact, the assessment and treatment of swallowing disorders are complex procedures. Therefore, SLP ought to work as a team with families, caregivers, and patients to have success in the intervention (Arvedson et al., 2015; American Speech-Language-Hearing Association, n.d.)

7. Acoustic Analysis of sounds

Sound can be defined as a vibration traveling through the air as a sound wave. It results from a source of vibration that requires a material medium for its propagation, compressing the surrounding air molecules, squeezing them closer together, and then rarefying them, pulling them farther apart. When these changes in air pressure vibrate our eardrum, nerve signals are sent to the brain and are interpreted as sound (Foreman, 1990; Martins, 2005).

Frequency is the number of times that a wave cycle repeats per unit time, usually per second. It is measured in cycles per second, or hertz (Hz). About human's range of hearing, the values are from 20 Hz to 20,000 Hz. Although other frequencies exist, they are inaudible to humans. The perception of frequency is called pitch (Plack, 2013).

The maximum displacement of the vibrating particle from the mean position is defined as Amplitude (or intensity). It is measured in decibels and the human ear interprets this strength of a sound wave as volume or loudness (Martins, 2005).

Acoustic analysis has been used as a tool for studying food textures, mainly through the sounds that are generated by mastication. They analyse the frequency and amplitude of the signal of this biological process. Over the last years, swallowing sounds have also been studied regarding their acoustic characteristics by different researchers (Taniwaki & Kohyama, 2012).

8. State of Art

Currently, the ability to detect dysphagia in the bed remains limited (Santamato et al., 2009).

There are several ways to assess swallowing skills that can be used at an early stage. Cervical Auscultation is one of the techniques proposed to complete the clinical evaluation of dysphagia, although it still presents as subjective method (Balasubramanium & Bhat, 2012; Bergstrom et al., 2013; Jestrovi et al., 2014; Morinière et al., 2008; Santamato, et al., 2009; Spaddoto et al., 2012). It is based on a sound analysis from which characterizes the swallowing process and decides whether the sound is normal or pathological (Borr et al., 2007). Should therefore contain objective information enabling an appropriate classification.

In recent years, health professionals and researchers have been using new techniques based on the sound analysis in order to develop alternatives and specific techniques for evaluation of swallowing.

Some authors consider that the acoustic analysis of the sounds of swallowing can help identify disease patterns (Santamato et al., 2009). Although there are different studies focused on this issue, it has not been defined benchmarks for swallowing sounds, nor irrefutable theories to explain the anatomical and physiological causes and acoustic characteristics of these sounds yet.

8.1. Methods and materials

8.1.1. Selection Criteria

They were included all studies that refer and analyze the swallowing sounds of healthy or dysphagic adults, collected by cervical auscultation using a digital stethoscope or a microphone. In pathological cases, dysphagia must be caused by neurological disease, including stroke mandatorily. Inclusion criteria for selecting articles were: studies involving healthy adults; studies involving adults with dysphagia after stroke; cervical auscultation as a method of collecting swallowing sounds that must be recorder through microphone or a digital stethoscope; articles written in Portuguese, English or Spanish, with less than 10 years from their publication date.

Articles with no summary available or articles concerning other diseases were excluded, as well as those which sample comprises individuals with dysphagia without any reference to stroke as a possible cause of this disturbance, and studies involving only young people. Studies that had used other methods different from cervical auscultation, as accelerometer or manometer, were also excluded.

8.1.2. Strategy of research

The research method to search for articles was based on the online library PubMed with the following keywords: “Deglutition”, “Swallowing”, "Deglutition Disorders”, “Dysphagia”, “Respiratory Aspiration”, “Adults”, “Cervical Auscultation” and “Acoustic analysis”. Some articles were found on the Scientific Electronic Library Online – SciELO, which is a reference search engine in SLP. In this platform, the research keywords were “Deglutition” and “Cervical Auscultation” (Appendix 2).

8.1.3. Selected Studies

Studies that have emerged from the query (n=269) were analyzed and selected by a reviewer. Initially, they were read all the titles and abstracts to apply the selection criteria: 252 articles were excluded (n=17). A full reading of the articles was necessary to reapply the criteria for inclusion and exclusion previously defined. They were excluded 9 articles because of using equipment to collect the sounds of swallowing different from digital stethoscope and microphone (such as accelerometer); studying judgements and decisions about CA made by experienced professional; and using methods based only on analysis of breathing sounds. One article was included from the online library Scielo (n=9) (Figure 3).

The bibliography from all the selected articles was also analized to try to include important information from older articles about this topic. Only four articles were assessed, however their researchers used accelerometer as a method to collect swallowing sounds.

8.1.4. Studies characteristics

The following properties were analysed from the selected articles: age and size of the sample, used materials for collecting the sounds of swallowing, characteristics of food (volume and consistency), collection methods, data analysis results (number of bursts, anatomophysiological events identified, duration and frequency of swallowing sounds) and author’s conclusions.

About the characteristics of the studies found, most of the sample has a small size and they were included individuals of all ages. Seven studies analyzed sounds collected only from healthy individuals. Two studies compared swallowing sounds between individuals with dysphagia and healthy subjects. All researchers used a microphone or a digital stethoscope to collect the sounds and laid them into a computer. There were tested different food volumes and consistencies in the studies. Not all authors analyzed the origin of swallowing sounds.

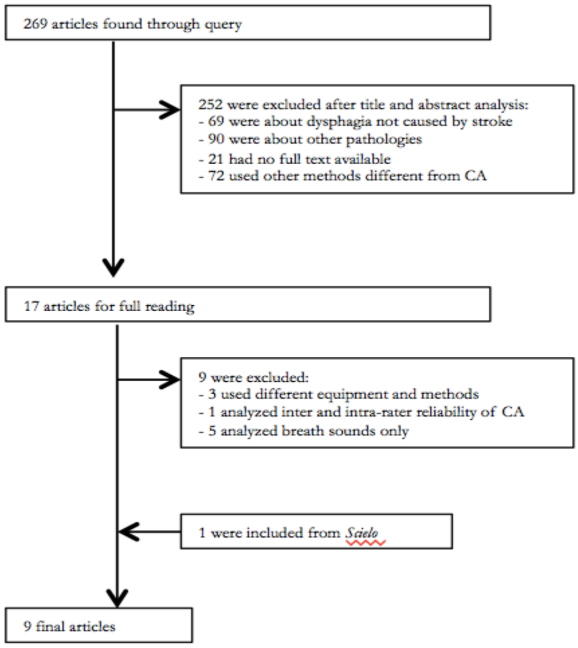


Figure 3: Scheme of the selected articles from query.

8.2. Results and discussion

Although the sound of pharyngeal swallow has been studied in normal subjects since the 1960s, the studies that focus on the anatomical origin of the sounds date from the 1990s (Morinière et al., 2008).

In the last 10 years, researches have been continuing to study the swallowing sounds trying to improve the clinical evaluation of dysphagia and the found results of them are presented below.

8.2.1. Health condition, age and gender

Almost all studies only included health people (Borr et al., 2007; Hammoudi et al., 2014; Morinière et al., 2006; Patatas et al., 2011; Santamato et al., 2009a; Spaddoto et al., 2012; Taniwaki & Kohyama, 2012) with a varied sample size, from n=6 to n=60; Patatas et al. (2011) had observed 164 subjects. Borr et al. (2007) and Santamato et al. (2009) also included dysphagic subjects.

Women and men with different ages participated in the studies.

Morinière et al. (2006) observed twenty healthy men and ten women with an average age of 37,4 +- 12 and 35,5 +- 11 years respectively.

Borr et al., (2007) included swallowing sounds of 50 healthy individuals distributed by two groups (young and old subjects), and sounds of 14 patients with dysphagia. Thirteen women and 12 men, with no neurologic and swallowing disorders historical, represented the “older group”, and the mean age of them was 76.2 years (range = 60–97 years). The average age of participants with dysphagia was 71.3 years (aged between 44-89 years). They all have history of dysphagia associated with cerebrovascular diseases. All subjects had clinical signs of dysphagia and aspiration risk.

Leslie et al. (2007) observed 19 healthy volunteers (8 men, 11 women; median age = 33 years; range 18-73). (Morinière et al., 2008) also enrolled healthy subjects (10 men and 5 women with average age of 29.5 ± 8 years; between 24 and 50 years old) and they were performed 75 recordings in all of them.

Santamato et al. (2009) recruited 60 healthy volunteers, 10 men and 10 women, which were divided into 3 age groups: group A (age range 18–35 years), group B (age range 36–59 years), and group C (age 60 years and older). Fifteen subjects with dysphagia caused by neurological diseases formed the pathological group.

Patatas et al., (2011) had more participants in their study; they included 88 women and 76 men between the ages of 6 and 85 (average age=32,9 years). Spaddoto et al. (2012) and Hammoudi et al. (2014) observed 14 and 23 healthy subjects, respectively, between the ages of 20 and 59 years. On the other hand, Taniwaki & Kohyama (2012) observed only 6 subjects (3 men and 3 women) in their 30s and 40s.

Analysing the range of ages of the studied groups, it is possible to observer a huge difference between the participants. In this study, they will be included women and men with more than 45 years old, considering the range age of stroke (American Heart Association, 2012; Hall et al., 2012; Sousa-Uva & Dias, n.d.).

This selection is important to trying to restrict and standardize the sample of this study and for a future comparison of health and dysphagic population.

8.2.2. Equipment and procedures

Researchers selected similar procedures to collect swallowing sounds. All of them used a computer device to store the signals collected by a microphone ((Spaddoto et al., 2012; Hammoudi et al., 2014; Morinière et al., 2006, 2008; Patatas et al., 2011; Santamato et al., 2009; Taniwaki & Kohyama, 2012) or an electronic stethoscope (Borr et al., 2007; Leslie et al., 2007).

In all studies, researchers placed the collected device directly under the right side of the cricoid, in a fixed position, by using an elastic tape.

Some swallowing sounds were recorded during VFSS (Borr et al., 2007; Spaddoto et al., 2012) or FEES (Leslie et al., 2007).

Morinière et al. (2006) had an omnidirectional microphone (Electret tie-clip Sonymicrophone, frequency range = 50–18,000 Hz) connected to an amplifier linked to a computer audio acquisition card.

In the study conducted by Borr et al. (2007), each swallowing was recorded in a controlled manner through VFSS. The sounds were collected into a computer via the Audiorecorder program that allowed the creation of mono line-in with a resolution of 16 bits at a sampling rate of 44.1 kHz. The stethoscope's high-pass filter was activated during recording. The sound files were displayed as waveforms and were interpreted by making use of Soundforge 6.0 *software*.

Leslie et al. (2007) recorded the sounds into a computer device using a Littman Cardio III stethoscope. The auscultation sounds were recorded at 44100 Hz. FEES and CA were performed simultaneously. The sounds and video were synchronized at a later time. They also used an external pressure transducer to measure the direction of airflow.

In the study of Morinière et al. (2008), they used X-ray camera joined to a computer's video card. Swallowing sounds were collected by an omnidirectional microphone (Electret tie clip microphone, 50–18,000 Hz; Sony, Japan), which was connected to a preamplifier linked to an audio acquisition card.

Santamato et al. (2009) utilized a notebook computer connected to a microphone MC-1200 (Trust International BV, Dordrecht, the Netherlands) that was used to collect the swallowing sounds. The acoustic signals, which were stored in the notebook computer, were posteriorly processed by the Fast Fourier Transform (FFT)-based Praat *software*. For the processing of the signals, it was defined in the *software* the following parameters: window length 0.005 sec; maximum frequency 5000 Hertz (Hz); 20 Hz frequency step; window shape: Gaussian; time-step 0002 sec.

A microphone connected to a sound card was used in the study conducted by Patatas et al. (2011). The sounds were recorded using specifics *software* (Sound Forge 4.5 and Praat 405).

Spaddoto et al. (2012) collected the sounds with a microphone that was connected to a sound table (Wattsom®) to amplify the signal. The information was stored into a DVD recorder device that was connected to the sound table. VFSS and CA were performed simultaneously.

To collect cervical sounds, Hammoudi, Hernandez, et al., 2014) made use of a microphone (Electret tie clip microphone, 50–18,000 Hz; Sony, Japan) connected to a sound card of a personal computer. The *software* "Cool Edit Pro" (Syntrillium *Software* Corporation, Phoenix, AZ, USA) was used to analyze each sound by a single investigator.

Taniwaki & Kohyama (2012) collected swallowing sounds using a controlled piezoelectric microphone (SH-12iK, Nanzu Electric Co. Ltd., Shimoda, Japan), offered commercially for dysphagia diagnosis. The sounds were sampled at a rate of 48 000 Hz through computer soundboard software, and then stored on a computer using a data logging developed in LabVIEW (National Instruments, Austin, TX).

Considering the fact that all researchers followed similar procedures and equipment to collect and record swallowing sounds, the methodology of the present study will be based on them.

8.2.3. Volumes and consistencies of food

Morinière et al. (2006, 2008) selected, in their two studies, 10 ml of 50% barium sulfate and 50% water (liquid consistency). Borr et al. (2007) also asked the participants to drink three servings of 10 ml of water, by their own hands. Besides water (5ml and 10ml) Patatas et al. (2011) observed swallowing saliva.

Another authors (Leslie et al., 2007) chose three boluses, each of 5ml and 20 ml volumes of blue dyed water and 5 ml yogurt. The liquids were measured by a graduate syringe and pouring into a small cup. The researchers asked participants to drink in one swallow.

The consistencies and volumes chosen by Santamato et al. (2009) were solid, (5g sandwich loaf); semi-solid (10g pudding); semi-liquid (10g yogurt); and liquid (10g water, not sparkling).

Spaddoto et al. (2012) asked the participants to swallow two consistencies with different volumes: 7 ml of liquid consistency (barium sulfate) and 10 ml of pudding consistency (50ml of barium sulfate and 4,5g of thickener).

Taniwaki & Kohyama (2012) tested the swallowing of 6g of liquid, semi- liquid and solid.

Hammoudi et al. (2014) selected three different consistencies to study: water at room temperature, unsweetened yogurt and reconstituted mashed potato (Mousline®, 125 g in 250 ml of milk and 500 ml of water at 30 °C; dynamic viscosity measured by the Brookfield method: 50,000 mPa s). All participants swallowed 2ml, 5ml and 10ml samples of the three consistencies.

In sum, there is a small variability in volumes and consistencies studied. Most of the researchers selected a volume of 10 ml; the swallowing of liquid consistency were analysed in all the studies.

8.2.4. Acoustic analyses

Not all authors analysed the swallowing sounds related with anatomical or physiological events. Almost all of them analysed the number of burst in their studies, even though it has been found a huge variability in the results (Table 2; Table 3).

In the study carried out by Morinière et al. (2006), sounds were classified into a first SC (SC1), a second SC (SC2), and a third (SC3). The intervals were classified as I1 between SC1 and SC2 and I2 between SC2 and SC3. In some of the data analysed they found inconsistently sounds at the beginning of the recording that were different in duration and aurally from SC1 For Men (M) and women subjects (W) it was calculated the mean total duration of each sound (T), the mean duration of the SC, and the mean duration of intervals, in milliseconds (msec) (Table 2).

Based on other previous studies, Borr et al. (2007) defended seven parameters associated to anatomophysiological events that occur during a swallowing: Onset time (ON) - Period of time from initiation of deglutition apnea to leading edge of first burst; Deglutition apnea (DA) - Duration of time from initiation to the end of deglutition apnea; First Burst (1B) - Duration of initial burst ; Second burst (2B) - Duration of second burst; Bolus Transport Signal (BTS) - Duration of time from leading edge of first burst to trailing edge of second burst; Offset Time (OFF) - Period of time from trailing edge of second burst to end of deglutition apnea; and Deglutition (D) - Number of gulps used to gulp down the bolus. The mean values of Younger (Y) and Older (O) group are presented in Table 2. They identified 2 main bursts (Figure 4) that seem to be correlated with the transport of the bolus through the pharynx (Borr et al., 2007).

Other researches (Leslie et al., 2007) had previously defined 11 physiologic events and 5 components of swallowing sounds (Table 3).

The physiologic events are the following ones: ApneaStart - Apnea onset, i.e., cessation of nasal airflow (from airflow); EpiStart - start of epiglottis movement away from rest (from video); EpiPost - epiglottis hitting the posterior pharyngeal wall preswallow (video); Whiteout - whiteout onset indicative of pharyngeal contraction (video); EpiReturn - return of the epiglottis to resting position (video); ApneaStop - apnea end, i.e. resumption of nasal airflow (airflow); Spillage - bolus entering the valleculae early (video); BolVal - postswallow residue in the valleculae (video); BolPS - postswallow residue in the piriform fossae (video); Pen - penetration of material into the laryngeal vestibule (video); Asp - aspiration of material below the true vocal folds (video).

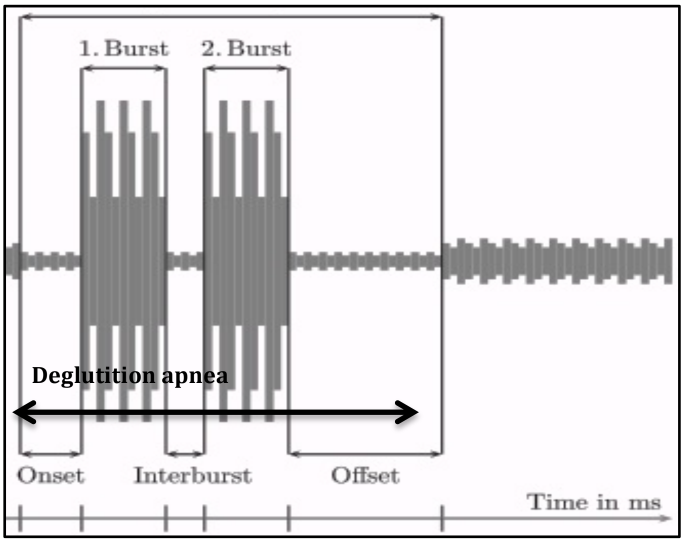


Figure 4: Scheme of deglutition waveform. Adapt. (Borr et al., 2007)

About the components of the sound, the results are the following ones: PreClick - start of epiglottis movement away from rest (from video), Lub and Dub - a distinctive "heart-like" Lub-Dub sound during swallow; to be marked it must be separable, i.e., it had to be possible to hear both Lub and Dub; Misc - midswallow sound, after Lub-Dub, but audibly before the onset of the prebreath sound or postapnea breath, often a gurgle ; Click - prebreath sound just before the postapnea breath, often a dull click; Breath - postapnea expiration onset.

As they only studied healthy subjects there were no instances of spillage, penetration or aspiration, and few usable measurements of the epiglottis hitting the posterior pharyngeal wall preswallow, postswallow residue in the valleculae and postswallow residue in the piriform fossae for meaningful assessment (Leslie et al., 2007).

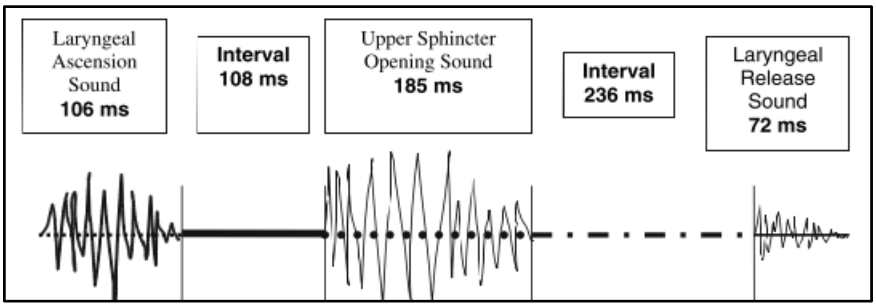


Figure 5: Profile of pharyngeal swallowing sound in normal subjects. Adapt. (Morinière et al., 2008)

Morinière et al. (2008) selected and analyzed three sound components according to the position of the bolus and the anatomical structure movements: (1) the Laryngeal Ascension sound (LAS) when the bolus was in the oropharynx and/or hypopharynx, (2) the upper esophageal sphincter opening (USO) and the bolus was going through the sphincter, and (3) the laryngeal release sound (LR) and when the bolus was located in the esophagus. They also analysed the average duration of the interval between the LAS and the USO (I1) and between the USO and the LR (I2) (Figure 5). The results are present in Table 2.

They identified the average duration of pharyngeal movements (830 ± 150 ms) was greater than the duration of pharyngeal sound (690 ± 162 ms), which ended sooner (Morinière et al., 2008).

Santamato et al. (2009) measured different components of the acoustic signal, such as total duration of a swallowing sound, frequency characteristics (Hz) of that sound and its acoustic power (dB).

Considering the main goal of this study, it will only be mentioned their information about the duration of a swallow and its frequency characteristics. Each swallowing was identified by breath sounds (the beginning and the end of apnea) and the results of duration of sounds can be observed in Table 2. They identified 4 main burst divided by mute intervals (Figure 6). It wasn´t found objective information about the association between anatomical events and swallowing sounds.

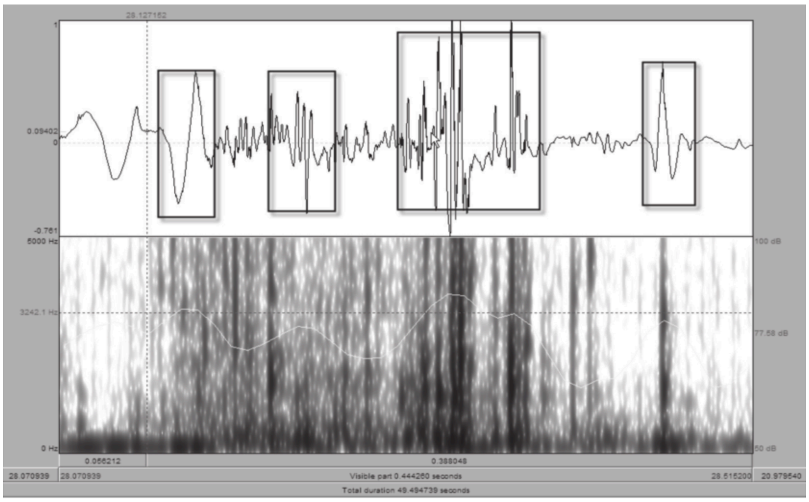


Figure 6: Acoustic analysis of 10 ml of water in a healthy subject. Adapt. (Santamato et al., 2009)

Patatas et al. (2011) analyzed visual and auditory proprieties of the sounds. Observing the great changes in spectrogram, they identified two main swallowing bursts and then measured the duration between the two bursts (T), the duration of apnea (DA) and ratio T/DA. The mean duration of swallowing sounds are on Table 2. It wasn´t found any association with anatomophysiological events and swallowing sounds.

In their study, Spaddoto et al. (2012) identified 2 main sounds and a third sound that they couldn't quantify because it wasn't precise, and it seemed to be related to breath sounds (they only marked the beginning of the third burst). They measured the duration of each burst and the duration of the interval between each one (Table 2).

Hammoudi et al. (2014) used the nomenclature defined in a previous study conducted by Morinière et al. (2006): the first component (SC1) was associated with the rise of the larynx, the second (SC2) with the passage of the bolus through the superior esophageal sphincter (SES), and the third (SC3) occurred during the descent and the opening of the larynx. In Table 2 are displayed their results of mean total duration of sounds for boluses of 10 ml, 5ml and 3ml.

Researchers (Morinière et al., 2006; Patatas et al., 2011; Santamato et al., 2009) identified no statistically significant gender differences in swallowing sounds durations. Patatas et al. (2011) didn't find important association between age and duration of swallowing too.

About the consistency of the bolus, Santamato et al. (2009) denoted that duration of swallowing sounds varies according to the bolus volume: less viscous bolus and liquids had a shorter time of pharyngeal transit than semi-solids. Also, Spaddoto et al. (2012) observed lower results in duration of swallowing pudding.

However, they found variability in signals and they couldn't affirm any association between the consistencies of food and the duration of swallowing. They only describe that the two bursts had the same behaviour, that is, a first brief parameter and a second longer one (Spaddoto et al., 2012).

Patatas et al. (2011) concluded that the higher the volume the less is the duration between the bursts. The duration of apnea is greater when swallowing saliva, less when swallowing 5ml of water and even less with 10ml water.

Despite of Hammoudi et al. (2014) didn't present the results of each component of a swallowing sound, they mentioned that the duration of SC2 increased with volume and all three consistency of the bolus, without association between the two variables. The duration of SC2 was significantly longer for 10 ml of semi-solid than for 10 ml of water or yogurt. However, the total duration of swallowing sounds isn't influenced by bolus consistencies. They attribute higher importance to the SES that is related with SC2. The increase of bolus volume and consistency seems to cause an increase of SES opening duration and an increase in bolus passage duration through the SES.

Table 2: Results found in the articles regarding to mean duration of swallowing sounds in Healthy Subjects according to the consistency and volume of the bolus.

Authors (Years)	Morinière et al. (2006)	Borr et al. (2007)	Morinière et al. (2008)	Santamato et al. (2009)	Patatas et al. (2011)	Spadotto et al. (2012)	Hammoudi et al. (2014)
Mean Duration (SD), in *ms*, according to consistencies and volumes of the bolus							
Saliva					T=201,3 DA=1774		
Liquid							
3ml							T=411(155)
5ml					T=159,6 DA=1436		T=441(150)
7ml							
10ml	T=710(28) Men: T=750(260) C1 =100(60) C2=140(50) C3=90(50) I1=100(50) I2=170(100) Women: T=540(250) C1=90(40) C2=150(130) C3=60(30) I1=90(80) I2=240(130)	Younger OT=1.16(0.47) DA=1.18(0.59) 1B=0.14(0.07) 2B=0.2(0.17) BTS=0.35(0.14) OFF=0.52(0.55) D=1.16(0.47) Older: OT=1.08(0.28) ON=0,84(0.86) DA=1.77(0.9) 1B=0,17(0.1) 2B=0.2(0.12) BTS=0.44(0.21) OFF=0.49(0.39) D=1.08(0.28)	T=690(162) LAS=106(47) USO=185(103) LR=72(38) I1=108(44) I2=236(139)	T=438,1 (109,6)	T=176,5 DA=1531	B1=87.273 (6.40) I1/I2=82.13 (66.22) B2=112.93 (62.94) I2/I3=339.48 (127.16)	T=515(217)
Semi-liquid							
3ml							T=411(155)
5ml							T=441(150)
10ml				T=564.2 (168.2)			T=515(217)
Semi-solid							
3ml							T=411(155)
5ml							T=441(150)
7ml						B1=78.20 (37.53) I1/I2=95.33 (48.66) B2=85.50 (52.20) I2/I3=332 (145)	
10 ml				T=730.9 (72.2)			T=515(217)
Solid							
5ml				T=575.7 (90.3)			

SD: standard deviation; T: Total duration of swallowing sound; C: Components of the sounds I1: Interval between C1 and C2; I2: Interval between C2 and C3; OT: Onset Time; DA: Deglutition Apnea; B: Burst; BTS: Bolus Transport Signal; OFF: Offset time; D: Deglutition; LAS: Laryngeal Ascension Sound; USO: Upper Sphincter Opening Sound; LR: Laryngeal Release Sound; I1/I2: Interval between B1 and B2; I2/I3: Interval between B2 and B3.

Table 3: Resume of all articles about sample size, characteristics of participants, volume and consistency of the bolus tested in each study, and the characteristic of swallowing sounds, more specifically, the number of components and their relation with anatomophysiological events

Author (year)	Sample size (n)	Mean age (SD), in years	Volume of food	Consistency of food	Parameters and number of burst	Description of the CA sounds
Morinière et al. (2006)	30 HS	M:37,4(12) W:35,5(11)	10 ml	50% barium sulfate and 50% water (Liquid)	6 parameters (3 burst)	1. **P1**: item with no description 2. **SC1:** item with no description 3. **IT1**: period of time between SC1 and SC2 4. **SC2**: item with no description 5. **IT2**: period of time between SC2 and SC3 6. **SC3:** item with no description
Borr et al. (2007)	50 HS 14 DS	3 groups Y: 30.9 O: 76.2 DS: 71.3	10 ml	Water (Liquid)	7 parameters (2 bursts)	1. **ON:** Period of time from initiation of DA to leading edge of 1B 2. **DA:** Duration of time from initiation to the end of DA 3. **1B:** item with no description 4. **BTS:** Duration of time from leading edge of 1B to trailing edge of 2B 5. **2B:** item with no description 6. **OFF:** period of time from trailing edge of 2B to end of DA 7. **D:** Number of gulps
Leslie et al. (2007)	19 HS	33	5 ml 20 ml	Blue dyed water (Liquid)	5 components	1. **PreClick:** no evidence 2. **Lub and Dub:** seems to be related with the "whiteout" event (indicative of pharyngeal contraction) 3. **Misc:** no evidence 4. **Click:** no evidence 5. **Breath:** seems to be related with ApneaStop (resumption of nasal airflow)
			5 ml	Yogurt (Semi-liquid)		
Morinière et al. (2008)	15 HS	29.5(8)	10 ml	Barium suspension (Liquid)	5 parameters (3 bursts)	1.**The laryngeal ascension sound (LAS):** ascension of the hyoid bone when the bolus was located in the oropharynx and/or hypopharynx. 2.Duration between LAS and the upper-sphincter opening sound 3.**The upper-sphincter opening sound**: opening of the upper sphincter and the bolus was going through the sphincter. 4.Duration between the upper-sphincter opening sound and the laryngeal release sound. 5.**The laryngeal release sound:** descent and the opening of the pharynx and the larynx and the bolus was located in the esophagus.

Table 3: Resume of all articles about sample size, characteristics of participants, volume and consistency of the bolus tested in each study, and the characteristic of swallowing sounds, more specifically, the number of components and their relation with anatomophysiological events

Santamato et al. (2009)	60 HS 15 DS	3 groups A:18-35 B:36-59 C≥60 DS:73.1(8.2)	5 ml	Sandwich loaf (Solid)	4 bursts	They analyzed 3 variables for each swallow*: - The total duration of the swallowing sound (DSS) - The peak intensity (PI) of the acoustic signal recorded - The peak frequency (PF)
			10ml	Pudding Yogurt Water		
Patatas et al. (2011)	164 HS	32,9	-	Saliva	4 parameters (2 burst)	1. First Burst: item with no description 2. T: Duration between the two bursts 3. Second Burst: item with no description 4. dA: Duration of Apnea
			5ml 10ml	Water		
Spadotto et al. (2012)	14 HS	31(10)	7 ml	50mL barium with 4.5g of thicken (Pudding)	5 parameters (3 burst)	1. First burst: item with no description 2. Period of time from first burst to second burst. 3. Second burst: item with no description 4. Period of time from second burst to third burst. 5. Third burst: item with no description
			10 ml	Liquid barium		
Taniwaki et al. (2012)	6 HS	30-40	6g	Water Yogurt Konjac jelly (Solid)	?	They investigated the frequency characteristics of swallowing sounds
Hammoudi et al. (2014)	23 HS	28(10)	5 ml 10 ml	Flat water Yogurt Similar to mashed potato	5 parameters (3 main components)	1. **SC1**: Rise of larynx – it was analyzed the duration of the event 2. **IT1**: period of time between SC1 and SC2 3. **SC2**: Passage of the bolus through the superior esophageal sphincter – it was analyzed the duration of the event 4. **IT2**: period of time between SC2 and SC3 5. **SC3**: the descent and the opening of the larynx – it was analyzed the duration of the event.**

SD: Standard Deviation; HS: Healthy Subjects; DS: Dysphagic Subjects; O: Older group; Y: Younger group; M: Men W: Women
* It wasn´t found any objective information about the association between anatomophysiological events and swallowing sounds.
**They used nomenclature that was taken from Morinie`re, 2008.

Morinière et al. (2008) determined the origin of three main sound components of pharyngeal swallowing related with anatomical structures and the position of the bolus The outcomes suggested that when the bolus was in the oropharynx, the larynx was at its highest point, in a fixed position and it is weaker in intensity. The transit of the bolus in the oropharynx seems to explain the formation of a sound. They couldn't provide an explanation for the origin of sound when the bolus was located in the esophagus. However, movements that occur in the soft palate and in the base of the tongue may have influence in the origin of the sounds

Leslie et al. (2007) identified some association between the pre-click and the onset of apnea; the pre-click and the start of epiglottic excursion; the click and the epiglottis starting to return to rest; and the click and the end of the swallow apnea. They can´t prove that a specific physiologic or anatomical event can cause an explicit sound. Considering a sound is caused by some biological phenomena, they might to occur at the same time.

Santamato et al. (2009) identified the mean PF and had observed different values (Table 4); hence they didn't find any conclusion about this parameter. Taniwaki & Kohyama (2012) performed only frequency analyses of the swallowing sounds associated with food consistency: liquid (water), semiliquid (yogurt), and solid (konjac jelly). They developed an FFT-based frequency analysis program to obtain a spectrum of a specific region of time domain swallowing signals. They shown a set of time-series swallowing sound signal for water with three important components according to Morinière et al. (2008). They also found that the FFT spectra of swallowing sounds in the frequency range between 400 and 1000 Hz differed among food samples, suggesting that swallowing sounds are dominated by low frequencies (Taniwaki & Kohyama, 2012).

Table 4: Found values of Peak Frequencies of swallowing sounds in Healthy Subjects

Author (year)	Santamato et al. (2009)
Peak Frequency (SD), in Hz	
Volumes and consistencies:	
10 ml liquid	3601.0(65.2)
10 ml semi-liquid	3226.2(452)
10 ml semi-solid	3164.3(503.1)
5ml Solid	2896.6(556.0)

SD: Standard Deviation

Only two authors (Borr et al., 2007; Santamato et al., 2009) included sounds from dysphagic subjects in their studies and both found significant difference in the mean duration of swallowing between healthy and pathological sounds. Borr et al. (2007) considered the number of gulps the most reliable for distinguishing dysphagic from healthy swallow recordings. Dysphagic individuals usually need more than one gulp to swallow the bolus and they showed a shorter first burst. Santamato et al. (2009) mentioned that its values can be longer or shorter in pathological individuals than in healthy subjects according to age; they also considered that post-swallowing respiration is often different. Only Borr et al. (2007) presented results of a pathological swallowing (Table 5).

Table 5: Mean Duration (SD), in ms, in Dysphagic Individuals to 10ml of liquid

Authors (year)	Borr et al. (2007)
Volumes and consistencies	
	T=1.86(0.86)
	ON=0.9(1.05)
	DA=2.05(1.49)
	1B=0.11(0.05)
	2B=0.2(0.09)
	BTS=0.44(0.27)
	OFF=0.72(0.89)
	D=1.86(0.86)

As a conclusion, there still exist a controversy between researchers about swallowing sounds origin. Moreover, there are differences in the number of burst and parameters that could characterize a swallowing sound, as we can observe in Table 3.

There seems to be an agreement about no influence of age and gender. The characteristics of the bolus (volume and consistencies) may have an important effect in swallowing sounds behavior. Duration of swallowing sounds also seems to be an important parameter to characterize swallowing sounds.

Not a lot of studies were found regarding swallowing sounds in pathologic subjects.

According to all the researchers, CA should be used in assessment of dysphagia as a complementary method, even though swallowing sounds are still a subjective issue.

9. Study design and Methodology

9.1. Participants

The target population of this study is healthy individuals with over 45 years old, that will be included in a first group, and dysphasic adults post-stroke, who will be included in a second group.

To find healthy volunteers, people who are closer to the investigators will be contacted and asked them to participate in the present study. It will be searched some institution of seniors people in Porto and try to contacted them too.

Some healthy volunteers were recruited from a Senior Association on Porto and others were researchers' family members and friends.

They could be included in this group adults aged over 45 years old, male and female, in good health without any history of respiratory or swallowing disorder, eating or nutrition problem or neurological disorder.

The size of the sample of pathological individuals was dependent on the number of patients with the desired characteristics that during the collection period were to be monitored (inpatient or outpatient) at Unidade de Saúde Local de Matosinhos – Hospital Pedro Hispano.

They could be included in pathological group adults aged over 45, male and female, who presented oropharyngeal dysphagia post-stroke. Were excluded all individuals with structural changes that could interfere with the swallowing process (as laryngectomy), individuals with dysphagia associated with degenerative diseases or other medical conditions, as well as individuals with alterations of consciousness and low collaboration capabilities (such as dementia).

Have been asked to participate in the study all individuals with dysphagia internally referred to the ENT Service to perform FEES, who met the inclusion criteria. CA was performed simultaneously after their permission.

All participants signed informed consent after they were explained the study objectives and procedures. The impossibility of the participant writing, by presenting motor disorders or some kind of difficulty in communication, informed consent was signed by the person responsible.

In some cases of hospitalization, participants came alone and were unable to sign. In these situations, when they were orientated, it was decided to collect the digital brand to formalize the approval of the study.

9.2. Local Characterization

This study took place in USLM-HPH, at a doctor's office, without windows, entered in the ENT Service. Due to the dynamic of this service, which stemmed simultaneously queries specialty in nearby offices, often there was noise control difficult environment. Inside the room all those present were informed of the need to remain silent during swallowing to prevent alteration of evidence of the sound signal collected by stethoscope.

9.3. Resources

9.3.1. Human Resources

They were enrolled in the collected procedures two SLP: one of the professionals was responsible for placing and holding the stethoscope in the proper position throughout the examination as well as to signal with a click the intake of food in the mouth; the second therapist had to realize the swallowing tests, providing the different consistencies to individuals under study and giving some orders. An ENT doctor was also involved as the professional responsible for conducting the FEES.

9.3.2. Instruments collection

To collect the sounds, it was used an electronic stethoscope (Cardionics E-Scope II) and headphones attached to the stethoscope, allowing one of the professional to hear real-time swallowing sounds that were being collected. E-Scope II has a maximum amplitude or sound pressure level output without distortion of 120 dB at 100 Hz, which is about 30 times louder than an acoustic stethoscope (Cardionics Inc, n.d.).

A clicker was also used to signal food entering the mouth.

The equipment and *software* required for the realization of FEES, enabling the acquisition, visualization, manipulation and image recording, video and audio, was a 3.2 mm endoscopes *hardware* and Xion ® *software*.

An external soundcard (Creative) was used for filtering the signal, making the connection between the stethoscope and the computer (HP Pavilion 13-b001np) The computed was needed for the collection of the signal and its registration in the Audacity *software*.

9.3.3. Material resources

The professionals involved in the preparation and implementation of the exam needed gloves.

To prepared the food consistencies they used glasses, container used to put the necessary consistencies (thin liquid and pudding); spoons, utensil used to provide food to individuals in the study; and 10 ml syringes material used to measure the volume of food to be ingested by individuals in the study (5ml and 10ml).

About the consistencies, it was necessary water to test the liquid consistency and to prepare the pudding consistency; food thickener, powder used to thicken the water to pudding consistency; and Cookies (Bolacha Maria), food selected to test the solid consistency.

Blue food coloring was also required to impart color to consistencies prepared in order to differentiate food of secretions and anatomical structures.

9.4. Procedures

9.4.1. Ethical procedures for data collection

Prior to the delivery of the application to carry out this study, it was made a first contact with the Clinical Director of the ENT Service, ULS - Matosinhos. It was scheduled a meeting for presentation of the study, supported by a previously designed clinical protocol in order to realize the possibility of this being done at the institution in collaboration with hospital staff. After positive assessment by the Clinical Director, carried up another meeting with professionals who would be involved in conducting the study, including the ENT doctor responsible for carrying out the FEES and SLP of the Physical Medicine and Rehabilitation Service.

Progress was made with the delivery of formal authorization application letters to the Board of Directors and the Ethics Committee of ULS - Matosinhos. After a favorable opinion from the Ethics Committee, the Board of Directors authorized the request on January 20th of 2015.

From that moment, it began the process of data collection. To perform the AC during FEES, it was necessary to get authorization by individuals with dysphagia, or its officers, through informed consent.

Informed consent was given before the examination achievement to be signed, formalizing the authorization of participation in the study.

It is essential, from an ethical point of view, an early clarification of the purpose and objectives of the study through a "contact" of trust and responsibility. The investigator should ensure the interviewee that nothing will be brought to the public without their consent, that is, ensure data confidentiality. It should also ensure the right to privacy, protecting the anonymity of the participants using fictitious names or code (Máximo-Esteves, 2008).

9.4.2. Procedures for data collection

In order to streamline the process of data collection, the material was organized before the arrival of participants using a checklist (Appendix 1).

For the acquisition and storage of data from CA it had to turn on the computer and configure Audacity program. The electronic stethoscope was connected to the external sound card without any active filter, that it was connected directly to the computer. Audacity program was opened with the following settings to the waveform: mono line with a 32 bit float resolution at sampling rate of 44,100 Hz to avoid peak clipping of the acoustic signal. This characteristics was adapted according to previous studies (Borr et al., 2007).

After computer configuration, they were prepared three consistencies and volumes planned to be administered during examination: 5 ml and 10 ml of liquid (water); 5ml and 10 ml pudding consistency (with water thickener); and a solid consistency (Bolacha Maria). The consistencies were chosen according to previous studies (Balasubramanium & Bhat, 2012; Borr et al., 2007; Hammoudi et al., 2014; Leslie et al., 2007; Morinière et al., 2006; Morinière et al., 2008; Patatas et al., 2011; Santamato et al., 2009; Spaddoto et al., 2012). In all consistencies food blue dye was added to distinguish the food secretions and anatomical structures.

All participants had to move or be displaced to the ENT Service and might be accompanied by family or professional institution.

After proper introductions are made, participants were informed of all the procedures of examination and study objectives. If they were in agreement and willing to cooperate, they should sign informed consent to CA could be performed. It was not necessary to collect permits for FEES since this test integrates the institution's dynamics.

Through the medical records of participants, it was possible to have access to their personal data and medical history, collecting only information in relation to gender, age, and type of stroke. Their clinical records were also needed to inform if there were other important medical conditions.

During the examination, participants should remain seated. The professionals involved should be arranged in the room according to their function.

SLP responsible for holding stethoscope sat to the right of participants. And should remain in this position until the end of the examination to decrease any movements of the stethoscope. The stethoscope was secured on the lateral side of the neck onto the lateral border of larynx and trachea, after palpation (applied the 4-finger-method), which Takahashi et al. (1994) considered ideal.

This professional was also responsible for controlling, through visual information on the computer, the quality of the collected sound. As volume control of the stethoscope was difficult to adjust it was defined that the volume should be 0 at the beginning and then the button should be clicked 4 times to men and 10 to women. These numbers were defined after many experiences in normal people. However, it didn't work as a rule. Sometimes, it was necessary to increase or decrease the volume of the stethoscope in the course of the FEES.

In all the situations, a first test was made, with saliva swallowing, before the beginning of the exam to prevent loss of the signal information during it. The doctor only initiated the exam once it is ascertained that the acoustic signal was being properly collected on the computer. Auscultation was performed with simultaneous FEES.

A protocol was used to standardize collection procedures for healthy adults. The food consistencies were administrated in the following order: saliva, free gulp of thin liquid, 10ml of thin liquid, 5ml of pudding, 10ml of pudding and solid.

In view of the ethical issues, for the safety of participants enrolled in the pathological group, the selection of consistencies was made according to their swallowing skills and dysphagia severity. After that, each volume was given twice in succession with a 1 min break between swallows by the second SLP involved. The order of administration of foods to participants was dependent on their orofacial motor skills and previously known swallowing performance during the examination. It was used a spoon to present the pudding consistency and a cup to water.

It was necessary to create a strong beep (one click) to signal the chart record the intake of food in the oral cavity because FEES does not allow visualization of the oral procedure. This signal is important to the final synchronization process.

The acoustic signal of the CA was collected continuously throughout the examination and recorded in waveform in the Audacity program. The image of FEES was saved on the equipment being exported to an external drive for later manipulation.

9.4.3. Acoustic analysis

The collected recordings, audio and video, were analyzed by a single investigator.

First of all, it was grouped the individual subjects recordings in different computer folds to easily analyzed them. Each data was studied individually according to subjects and consistencies.

The videos were visualized on a free *software* to identify the anatomophysiological event and register its time.

All the sounds was opened with Audacity *software* and represented graphically through a *waveform* and *spectrogram*. It was measured the duration of the sounds and changes in frequency and amplitude of the acoustic signal. The sounds, which the acoustic signal was not corrected visualized or not clearly heard were discarded.

Video and audio were manual synchronized. Observing and listening the vowel /i/ production in the video, it was possible to identify T0 (Figure 7). The same was done in the waveform and then it was calculated the differences between them, in milliseconds (msec). The number obtain was used to add or subtract.

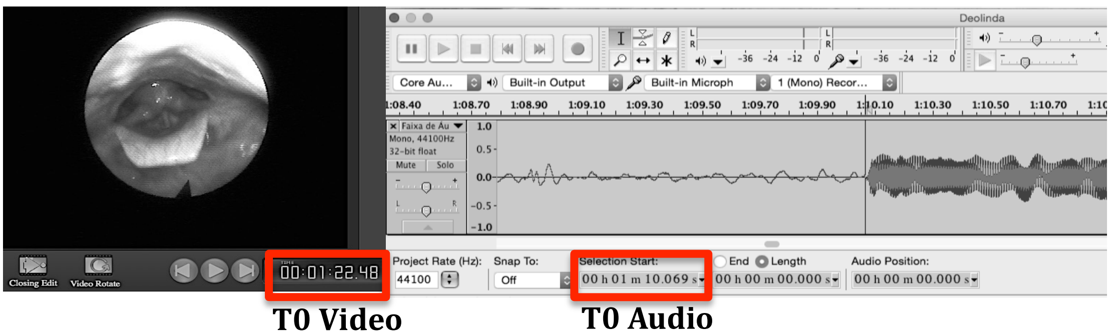


Figure 7: Example of vídeo and audio synchronization process.

Because of uncertainties found in all the previous studies regarding the anatomophysiological events that occur at the same time and quickly, it was chosen to focus on the most objective phenomenons that could be observed in FEES. Only three events were selected to analyze, according to Leslie et al. (2007): EpiSart, Whiteout and Epireturn (Tabel 6).

The number of sound components and the terminology to classify them is also unclear and there is no consensus found among investigators. Considering the study of Leslie et al. (2007), which describes sounds based on commonly terms used by experienced clinical using CA, it will be used the same nomenclature: PreClick (PC), Lub and Dub (LD), Misc (M) and Breath (B). The silences between each sound were called Interval (IT) 1 and 2 according to the time they took place (Tabel 6).

Table 6: Definition of anatomophysiological events and sound components

Event	Description
Anatomophysiological event	
EpiStar	Start of epiglottis movement away from the rest that are observed up to whiteout.
Whiteout	Pharyngeal contraction making impossibly to observe anatomical structures – whiteout onset.
Epireturn	Return of the epiglottis to resting position.
Sound Components	
PreClick	Any sound preceding lub and dub, excluding breath sounds
Interval 1	First silence time before preclick up to second sound (lub-dub, misc or click)
Lub and Dub	Similar to “heart-like” lub-dub sound during swallowing – it has to be possible hearing two distinctive bursts, lub and dub.
Interval 2	Silence after lub-dub up to second sound component (misc or click)
Misc	Midsounds, after lub and dub, but audible before onset prebreath sound, often a gurgle.
Interval 3	
Click	Prebreath sounds just before the postapnea breath.
Breath	Sounds of breath after apnea - postapnea expiration onset.

About the component “time”, for each bolus and saliva it was measured the total duration of swallow (DS) observed though FEES and the total duration of the each sound of swallowing (DSS), with and without Oral Transit Time (OTT). To define the DSS, it was necessary to observe the *waveform* and lab it from the beginning to the end of the signal.

It was also measured the duration of each anatomophysiological event of a swallow, according to Table 6, through FEES. The duration of each sound component heard by the investigator was defined using labs in the waveform, observing the graphic behavior, according to Table 6 too. It was measured the duration of each sound component and the interval between them. Time was analyzed in milliseconds (msec).

After hearing the sound, the investigator noted the numbers of changes perceived, determining the parameters part of each swallow. Then, it was compared the sound and anatomophysiological events, through each lab previously used in the waveform, to search for a possible association between both components (Figure 8).

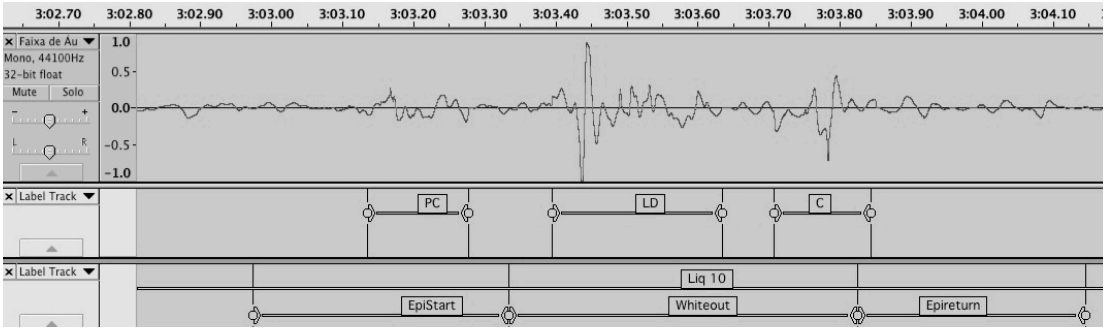


Figure 8: Example of acoustic analyzed using Audacity *software* with label tracks correlating anatomophysiological events and sound componentes.

The frequencies values of swallowing sounds were extracted from Audacity *software*, which were related with amplitude values. According to these data, they were calculated the mean values of signal variation in frequency domains according to different consistencies.

9.4.4. Statistic analysis

Considering the impossibility to calculate the most indicated size of the sample for this study, it was the used a Russ Lenth's power and sample-size's test (Lenth, 2006).

Remaining statistical analysis was performed using the Statiscal PacKage for Social Sciences - SPSS (version 24).

Normality of distribution was verified by a Shapiro-Wilk (the most indicated test to small sample) and homogeneity of variances was verified by a Levene test for all parameters. Friedman's test was used to compare all variables. Test-t was used to compare saliva and free gulp thin liquid and free gulp thin liquid. It was used the same procedures to compare healthy and dysphagic groups. To compare 5ml of pudding with 10ml of pudding it will be used the Wilcoxon's test.

The anatomophysiological events were analyzed using statistical inference through calculation of the lower and upper limits of the 95% confidence intervals for a proportion. To calculate the results it was used an appropriated *software* (Richard Lowry, 2001).

10. Results

10.1. Sample description

Thirty subjects participated in this study affording 60 data to analyze, 30 videos and 30 sounds records. Only 20 data could be included (7 sounds were uncorrected recorded by the *software* and 3 videos were not stored by the collected equipment).

Considering the individuals involved, there were 5 men and 15 women (n=20), with an average age of 55+-5 and 55+-7 years old respectively. Ten patients with oropharyngeal dysphagia post-stroke (n=10), six men and 4 women, with an average age of 67,5 were included in the pathological group of a pilot study.

For each subject it was tasted the swallowing of saliva, free gulp of thin liquid, 10ml of thin liquid, 5ml of pudding, 10ml of pudding and solid. Therefore, a total of 120 swallowing sounds were expected to analyze. Two saliva swallowing sounds, one free liquid and one 10ml of liquid were excluded because they were imperceptible, resulting in 116 swallowing sounds from 20 subjects.

For a specified sample size of 20 individuals (n=20), a power of 0.8 (80%) and a significant level of 0.05, estimating a SD=328, it will be found a difference of 130 msec between the mean values of the duration of swallowing of the five consistencies. These values were calculated from Russ Lenth's power and sample-size page (Lenth, 2006).

10.2. Anatomophysiological events and sound components analysis

All phenomenons defined, Epistart, Whiteout and Epireturn were observed in all videos (100%) and their times were noted (Figure 9).

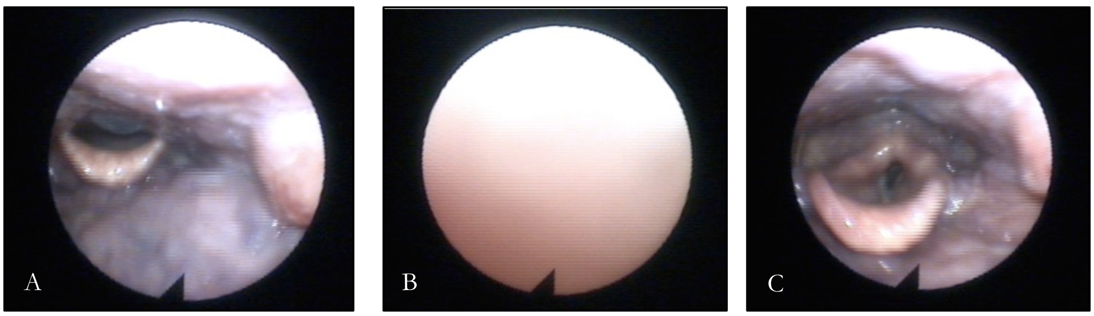


Figure 9: Images from FEES showing the phenomenon of Epistart (A), Whiteout B) and Epireturn (C).

The first analyse of the swallowing sound records was done without any classification of the sounds and no separation between volume and consistency of the bolus.

The investigator listen the 116 records to identify the number of sounds of each swallowing.

Fifty-nine of the records presented three sounds during swallowing (50,9%), one sound was heard in three records (2,6%), in 22 records was identified two sounds (19%), in 28 they was found four sounds (24,1%) and five sounds in four records (3,4%). These results are present in figure 10.

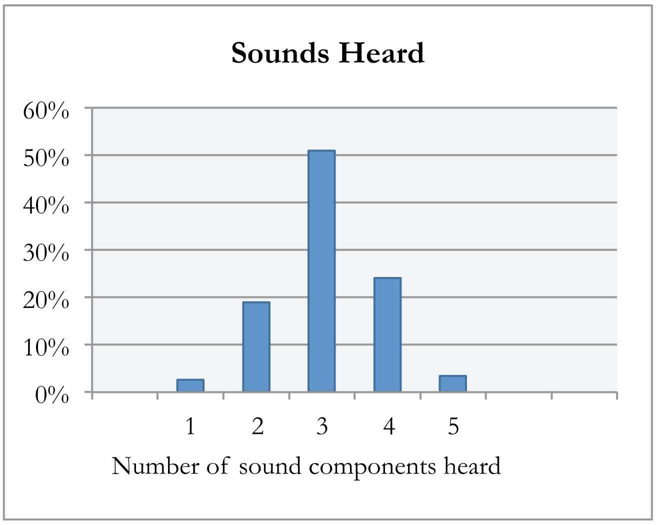


Figure 10: Number of sound components identified in the whole sample (116 swallowing records) analyzed in percentage terms, in healthy subjects.

Considering the classification of sound components, the investigator listen to the all records for a second time to identify the PC, LD, M and B. The following chart (Figure 11) shows the results found without separating the recordings according to the volumes and consistency of the bolus. LD and B were the most observed sound components, 113 times (94,2%) and 102 times (85%), respectively. PC was present in 40 recordings (66,7%), M in 34 (28,3%) and C in 67 (55,8%).

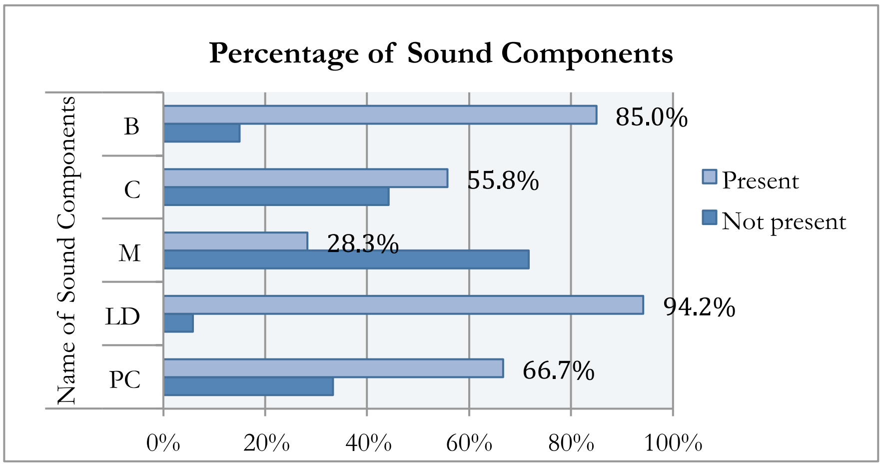


Figure 11: Percentage of sound componentes identified in the whole sample (116 recordings).

Posteriorly, it was investigated the number of times each sound component is observed according to different volumes and consistencies of the bolus. The results are present in Table 7.

Table 7: Frequency and percentage of sound components heard in the each swallowing according to the volumes and consistencies tested in healthy volunteers.

Bolus consistencies	**Saliva**	**Free gulp thin liquid**	**10 ml thin liquid**	**5 ml pudding**	**10ml pudding**	**Solid**
Frequency and percentage of sound components heard (%)						
Sound Components:						
PreClick	10(50)	6(30)	12(60)	14(70)	16(80)	18(90)
Lud-Dub	18(90)	19(95)	18(90)	20(100)	19(95)	19(95)
Misc	4(20)	9(45)	3(15)	14(70)	13(65)	15(75)
Click	5(25)	12(60)	9(45)	14(70)	16(80)	11(55)
Breath	15(75)	17(85)	16(80)	18(90)	19(85)	17(85)

10.3. Duration of anatomophysiological events and sounds from CA

Table 8 shows the global values of DS, DSS, DSS without OTT, and FSS, in healthy volunteers according to volume and consistency of the bolus. The number of gulps observed in each swallowing is also specified in the same table, in percentage terms. These parameters try to describe a swallowing through their acoustic characteristics.

Considering the video recordings, solid consistency presents the longest time (total duration of anatomophysiological events observed in FEES), with a mean result of 15562+-2590 milliseconds, with OTT. Excluding oral phase of swallowing, it was found a higher mean duration of 1838+-1464 to free gulp of thin liquid. The longest sound corresponds to 10ml of pudding with 846+-388 milliseconds.

Table 8: Global variables that describe the anatomophysiological events and the acoustic signal of swallowing sounds in healthy subjects.

Bolus consistencies	**Saliva**	**Free gulp thin liquid**	**10ml thin liquid**	**5ml pudding**	**10ml pudding**	**Solid**
Mean Duration (SD)						
Variables:						
DS, in msec	1091(203)	3799(1992)	2531(629)	4660(2321)	6408(1945)	15562(5290)
DSS, in msec	667(227)	795(431)	621(316)	742(222)	846(388)	641(305)
DS -OTT, in msec	1091(203)	1838(1464)	1191(339)	1068(174)	1165(260)	1030(192)
Min-max						
Variables:						
DS, in msec	810-1510	1663-9060	1450-4170	2000-11700	3400-10640	5680-29210
DSS, in msec	216-1137	216-1866	167-1473	356-1320	424-2013	273-1515
DS -OTT, in msec	810-1510	700-6970	830-2110	810-1410	800-1740	810-1550

Table 8: Global variables that describe the anatomophysiological events and the acoustic signal of swallowing sounds in healthy subjects.

Proportion (%)						
Number of gulps:						
1	100	85	100	65	40	50
2	-	15	-	35	35	35
3	-	-	-	-	25	15
+3	-	-	-	-	-	-

SD: Standard Deviation; DS: Total Duration of swallowing, according to FEES; DSS: Total Duration of Swallowing Sound from the beginning of the first sound component to the end of the last one; DS-OTT: Duration of Swallowing without the Duration of Oral Transit Time; FSS: Frequency of Swallowing Sound

About the number of gulps, all the subjects (100%) swallow saliva and 10ml of thin liquid in one gulp. The number of gulps increases in higher volumes of the bolus.

To test in Portuguese population if the duration average of swallowing sounds is the same in all consistencies of the volume it is necessary to confirm if data are probably normally distributed. Shapiro-Wilk test was used to test this parameter. As it can be visualized in Table 10, *p* is more than 0.05, in almost cases, except in 10ml of Pudding. Therefore, we cannot assume the null hypothesis to affirm that the all data are normally distributed.

Table 9: Outcomes from SPSS showing the resutlts of Shapiro-Wilk test.

Variable	**Consistencies and volumes of the bolus**	**Shapiro-Wilk**		
		Statistic	**Gl**	**Sig.**
DSS	Saliva	0.985	18	0.986
	Free gulp thin liquid	0.932	19	0.190
	10 ml thin liquid	0.934	19	0.201
	5 ml pudding	0.956	20	0.469
	10ml pudding	0.807	20	0.001
	Solid	0.904	20	0.049

A Friedman test was then carried out as a non-parametric alternative according to variables proprieties to see if there were differences between DSS consistencies of the bolus, with a result of p=0,197.

Considering a significance level of 0,05, we can accept H0 and assume that all consistencies have the same distributions.

T-test was used to compare the means between the two related groups, Saliva and Free gulp thin liquid, and to compare free thin liquid with 10ml of thin liquid.

For the first group, as the p-value is greater than 0,05 (p=0,211), then there is insufficient evidence to reject the null hypothesis and we can say the results are not significant at the 5% level. On the other hand, the second paired sample has p-value lower than 0,05 (p=0,032) and the null hypothesis is rejected in favor of the alternative hypothesis, with significant results at the 5% level. Therefore, we can say that mean duration of swallowing sounds are the same in the first two groups and that the mean duration of swallowing sounds in the second compared groups are different, with 95% of certainty (Figure 12).

As the second samples were not normally distributed, it was performed the Wilcoxon test to investigate whether swallowing sound has the higher duration according to the tested consistency (5ml and 10ml of Pudding). The p-value, 0,654, indicated that the median of the differences in the duration of swallowing sounds in 5ml of Pudding and 10ml of Pudding equals zero. There is insufficient evidence to reject the null hypothesis.

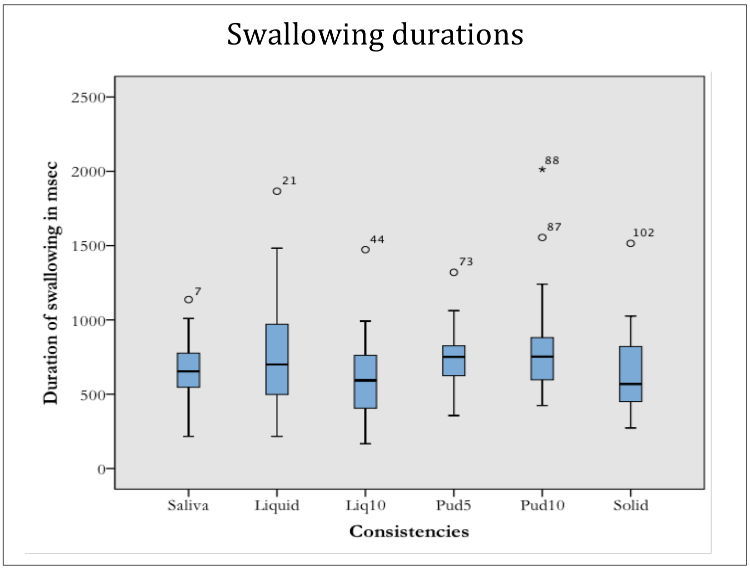


Figure 12: Boxpolt for outcomes about swallowing sounds durations according to different volumes and consistencies of the bolus.

After a global analysis of the anatomophysiological events and the sounds of swallowing, it was identified the mean duration of each phenomenon visualized through FEES and each sound components identified in the *Audacity software*. In Table 11 it can be observed the mean results found according to different volumes and consistencies in healthy participants.

Table 10: Mean duration of anatomophysiological events and sound components according to different volumes and consistencies of the bolus in healthy participants.

Bolus consistencies	**Saliva**	**Free gulp thin liquid**	**10ml thin liquid**	**5ml pudding**	**10ml pudding**	**Solid**
Mean Duration of anatomophysiological events (SD)						
Phenomenon:						
EpiStart	278(107)	350(179)	331(99)	237(113)	255(101)	249(144)
Whiteout	640(192)	1175(1381)	651(307)	604(127)	669(196)	585(153)
EpiReturn	178(77)	263(138)	212(85)	262(109)	235(96)	233(103)
Mean Duration of Sound Components (SD)						
Sound Components:						
PreClick	173(55)	159(103)	145(76)	94(15)	204(180)	217(50)
Interval1	163(56)	339(386)	112(94)	183(132)	251(210)	446(247)
Lud-Dub	360(134)	230(88)	334(111)	363(94)	336(102)	365(87)
Interval 2	60(9)	115(151)	152(183)	105(150)	187(310)	236(88)
Misc	158(66)	230(135)	220(94)	262(131)	365(107)	191(69)
Interval 3	93(90)	164(75)	99(104)	201(147)	163(141)	132(89)
Click	122(40)	141(49)	120(53)	148(54)	140(42)	127(27)

SD: Standard Deviation

The Witheout phenomenon presents the highest values in all bolus consistencies. The anatomophysiological events have different values from sound components. Considering the sounds, LD presents the highest average duration in almost consistencies tested.

10.4. Association between anatomophysiological events and each sound component heard

The swallowing sounds were grouped according to the nomenclature previously defined to search for any association between the anatomophysiological events and the sounds collected from AC. The results can be observed in Table 11. Briefly, no sound was listened in Transition to Epistart moment. PC appears 22 times (18,5%) at Epistart moment, LD occurs 94 times (78,3%) at whiteout moment, M is observed 15 times (12,5%) at whiteout and 11 times (9,2%) at transition to EpiReturn, and C occurs 12 times (10,0%) at Transition to Epireturn. No component was identified in 100% of swallows.

Table 11: Association between FEES and CA represented through frequency and percentage values according to the number of times each sound component is observed in each anatomophysiological event.

Sound Components	**PC**	**LD**	**M**	**C**
Frequency and percentage of sound components (%)				
Anatomophysiological event:				
Transition to Epistart	-	-	-	-
Episart	22(18,5)	-	-	-
Transition to Whiteout	9(7,5)	16(13,3)	1(0,8)	-
Whiteout	4(3,3)	94(78,3)	15(12,5)	12(10,0)
Transition to Episreturn	-	2(1,7)	11(9,2)	7(5,8)
Epireturn	-	1(0,8)	1(0,8)	47(39,2)
After return	-	-	1(0,8)	3(2,5)
Total Valid	35(29,2)	113(94,2)	29(24,2)	69(57,5)

The found values depend the number of times each sound component is identified in acoustic signal. Total valid values show the frequency each component is observed in the whole sample.

In global healthy people, the percentage of times that PC sound component coincides with Episart moment is, with 95 % of certainty, between 46% and 76% of the cases. LD coincides with Whiteout moment is, with 95 % of certainty, between 75% and 89% of the cases. With 95 % of certainty, the percentage of times that M sound component coincides with Whiteout moment is between 32% and 70% of the cases. Lastly, C coincides coincides with Whiteout moment is, with 95 % of certainty, between 56% and 78% of the cases.

Considering only the total valid results, the chart represented in Figure 14 resumes the association found between the anatomy and the acoustic signal. It is possible to observe that PC has its peak at Epistart moment and has some points at the first anatomophysiological events. LD has its peak ate whiteout moment. M has a flatter pyramid, with their main values from Transition to Whiteout to Transition to Epireturn. C has a peak on Epireturn, with some values before and after this point.

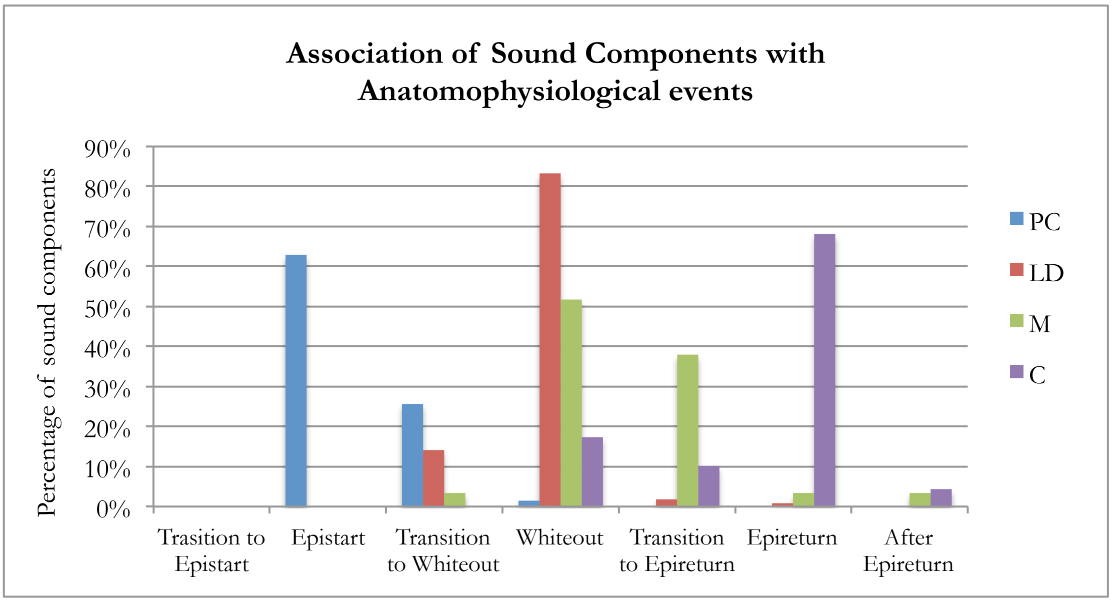


Figure 13: Percentage of sound components observed in each anatomophysiological events.

10.5. Acoustic characteristics of swallowing sounds

Figure 15 shows swallowing sounds' behaviour of all consistencies tested, describing the signal in the frequency domain. To achieve the results represented in this graph, they were calculated the mean values of amplitude in each frequency from all participants according to volume and consistencies of the bolus.

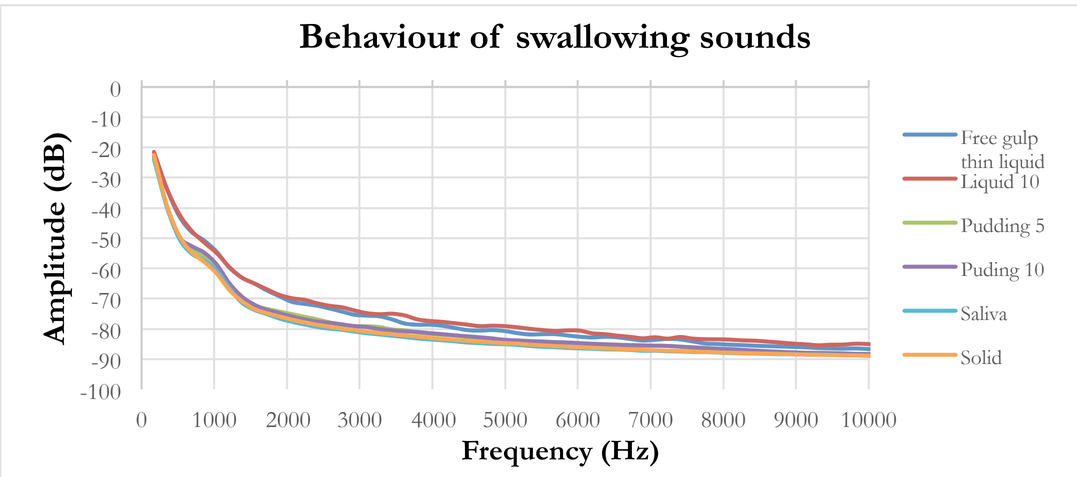


Figure 14: Average FFT spectra of swallowing sounds' behavior in terms of amplitude and frequency, according to consistencies of the bolus in healthy participants.

The most significant difference was observed in the frequency range between 517 and 3617 Hz. The highest amplitude of the spectrum in this range is for 10 ml of thin liquid followed by free gulp thin liquid and then, with closer values, saliva, 5 and 10 ml of pudding and solid.

10.6. Duration of swallowing sounds in Dysphagic subjects

The 10 sounds collected from dysphagic subjects have a mean total duration of 2058+-752 msec, results that can be observed in the following table (Table 13).

Table 12: Total duration of swallowing sounds of 5ml of pudding consistency from dysphagic participants, represented in msec.

Participants	DSS in msec
1	2374
2	1477
3	2566
4	2949
5	1671
6	3140
7	1724
8	1132
9	1016
10	2531
Total mean value (SD)	2058(752)

SD: Standard Deviation

Comparing the results between healthy and dysphagic subjects, in Figure 15 it is possible to visualize that healthy sounds values are shorter than pathological ones.

The diagram shows two different boxplot shapes and positions. The first one, from dysphagic subjects, suggests pathological sounds of swallowing have quite different duration time.

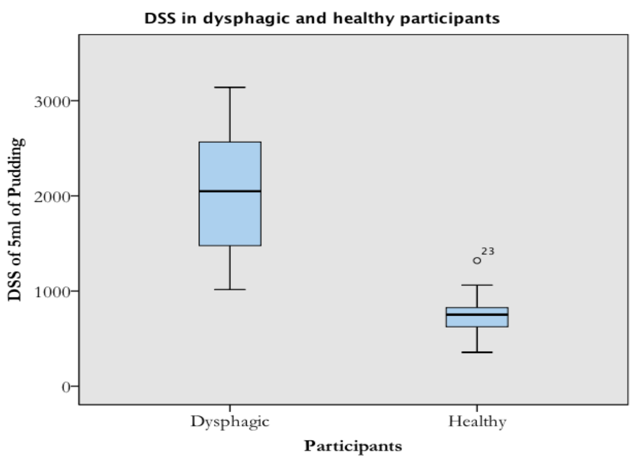


Figure 15: Boxplot correlating swallowing sounds from dysphagic and healthy participants.

The boxplot of the healthy sample suggests that overall sounds are closer to each other. About dysphagic group, 25% of the cases are below 1390 msec and above 2662 msec. Half of the cases are above and below 2049 msec. Healthy subjects have 25% of the cases below 609 msec and above 827 msec. Median are 752 msec, which means half of the cases are above and below this value.

After this interpretation, it is interesting to test in Portuguese population if the duration average of swallowing sounds is the same in healthy and dysphagic individuals.

To compare means of two samples it is necessary to confirm if data are probably normally distributed. Shapiro–Wilk test was used to test this parameter. As it can be visualized in Table 14, *p* is more than 0.05, in both cases. Therefore, the null hypothesis is probably true and we can be 95% certain that the data are normally distributed.

Table 13: Resume of SPSS outcomes about DSS from Dyspagic and Healthy participants to confirm if data are probably normally distributed

Variable	**Participants**	**Shapiro-Wilk**		
		Estatística	**gl**	**Sig.**
DSS5mlPuding	Dysphagic individuals	0.935	10	0.501
	Healthy subjects	0.956	20	0.469

After confirming data normality distribution, the evaluation of the equality of variances for DSS variable is also a necessary procedure through Levene's test finding a p=0.000. For a significance level of 0.05, we cannot assume the equality of variances for DSS. Therefore, it will be used the "Unequal variance" result (p=0.000). Since p-value is 0.000, the null hypothesis is rejected and we conclude that there are differences between DSS from the two groups at 5% significance level.

11. Discussion

Using acoustic technique to record swallowing sounds it was possible to collect important information about them such as: the number of sounds heard in each swallowing sound by the researcher and try to identify sound components in each sample sound, the duration of swallowing process and swallowing sounds according to different consistencies and volumes, possible anatomophysiological causes of swallowing sounds and characteristics of sounds in frequency domain.

About the collecting process data, in this study it was fallowed similar equipment and methods to previous studies. The same computer and stethoscope were used from the beginning till the end of the study to ensure greater consistency in sound data.

After some test with different stethoscopes, the Cardionics E-Scope II showed the best results when using paediatric plastic bell regarding to noise influence (such heart beating). Its small size was also an advantage when it is used in subjects with a short, thick neck.

According to Takahashi et al. (1994), the best signal-to-noise ratio is the later border of the trachea under the inferior border of cricoid. Many researchers used this position in their studies (Morinière et al., 2006) (Hammoudi et al., 2014). In the present study, it was placed the stethoscope in the same position. They also mentioned this position allows the highest average magnitude of the signal and the lowest standard deviation of the maximum peak sound of swallowing (Spaddoto et al., 2012).

No filters were used after the signal has been recorded, as it was done in Morinière's study (2006) to try to get sounds as close as possible to those we listen in clinical practicing.

Considering the previous researchers who identified no statistically significant gender and age differences in swallowing sounds durations (Morinière et al., 2006; Patatas et al., 2011; Santamato et al., 2009), in this study, the groups were created not based on these information but according to the presence of dysphagia.

The consistencies and volumes of the bolus used in this study with healthy subjects were also chosen according to previous studies. Because of ethic issues, as patients' swallowing skills were known by investigators, the selection of bolus and consistencies to test in this group were based on them. Therefore, liquid and solid were tested but not in the whole sample, which restricted the number of swallowing records for these consistencies.

To administrate food, it was used a spoon and a glass to avoid a disadvantages mentioned by Hammoudi et al. (2014), who used a syringe, and that changed the consistency of the bolus to a more fluid one because of the diameter of the syringe's nozzle. Using a spoon and a glass should also create a less artificial form of eating which made a more spontaneous swallowing process.

Different researchers have been studying cervical auscultation, but the results are difficult to compare. In spite of the attempt to follow similar procedures, previous studies are already different from each others, including the use of recording protocols.

About the identification of anatomophysiological events (Epistart, Whiteout and Epireturn) on video from FEES, all of them were identified in 100% of the cases, which means this exam allows an objective evaluation of these phenomena and can be used as an important tool in this study considering the main goals of it.

In the present study, sounds were heard by a SLP working in this field who identified and quantified three main swallowing sounds, in healthy subjects. These results match with previous studies (Hammoudi et al., 2014; Morinière et al., 2006, 2008; Spaddoto et al., 2012).

The number of sound components observed was different among subjects but also in individual subjects, which coincides with Morinière's findings (Morinière et al., 2006). These differences could be related with variability existing in the intensity of swallowing sound, what makes some of them not be possible to detect not by human hearing nor by the equipment. In fact, first sounds listened were the same as the researcher had identified in a second analysis when their classification was done. The noise caused by movements of the larynx or the stethoscope could also be confused as a sound component.

In this second analysis of the swallowing sounds, Lub-Dub, Breath and Click were the most observed sound components. Considering Lub-Dub is the same component as SC2 identified in previous studies, some findings could match. In this study, this component appears 94% of the 116 recordings and 100% in 20 recordings of 5ml of pudding. Also Hammoudi et al. (2014) find SC2 in 100% of the collected sounds.

Hammoudi et al. (2014) found different percentage values to sound components according to their presence in swallowing records with no influence of the consistency of the bolus, as it was observed in this study. Lub-Dub and Breath sounds keep the highest percentage of appearing. Breath sounds showed a regular behaviour and are present in almost data observed (85%), that is why it could give important information on clinical evaluation mainly identifying pathological swallowing. If this sound is changed, we could interpret that as a signal of residues of bolus in the pharynx.

It is also important to mention that no sound component was found on all recording made in this study, which means that the absence of sound does not necessary indicate abnormalities.

About the total duration of swallowing phenomena, considering only the video data, it was found different durations between swallowing with and without OTT. If we analyse the results including OTT, we can observe an increase of duration values according to the increase of volume and consistency. These results could be related with people strangeness and adaptation to consistency of the bolus, mainly because of the thickener characteristics, and mastication of the solid. If we observe swallowing duration without OTT, no differences were relevant between bolus consistencies, except free gulp thin liquid with a higher value. Hence this is the only consistency that subjects put into their mouth with no control on the volume of gulps and feed speeding, this higher values could be justify by these changes.

However, it wasn't found any significant differences in the total duration of swallowing sounds between consistencies and volume of the bolus too, except between two consistencies (free thin liquid and 10ml of thin liquid).

This results could be controversial that is why this should be studied with a larger simples. It would be probably needed a greater difference between volumes tested to have significant results.

Despite these findings, we can compare the mean duration of swallowing sounds from other studies to ours. For saliva we found a result of 667+-227 msec and Patatas et al. (2011) found a mean duration of 201,3 msec. For 10ml of thin liquid we fund a result of 621+-316 mesc that are similar to Morinière et al. (2008) who find a mean duration of 690+-162msec. Hammoudi et al. (2014) find a mean duration of 441+-150 msec for 5ml of pudding which are different from ours (742+-222). For 10ml of pudding Santamato et al (2009) find a duration of 730,9+-72,2 msec and theirs findings are the closest to our with a result of 846+-388 msec. Solid had a result of 575,5+-90,3 msec from Santamato et al (2009), which are closer to the result found in this study, which was 641+-305 msec. No previous results were found to free gulp thin liquid.

In fact, previous studies have controversial conclusions. Hammoudi, Hernandez, et al. (2014) didn't also find any differences in the total duration of swallowing sounds between consistencies and volumes of the bolus. On the other hand, other researchers (Morinière et al., 2006; Santamato et al., 2009; Spaddoto et al., 2012) mentioned that consistency of the bolus has an influence on the duration of swallowing sounds.

In some studies (Hammoudi et al., 2014; Patatas et al., 2011; Santamato et al., 2009) only the total duration of swallowing sounds was quantified and no details were done about the sound components which limit data analysis.

Other researcher studied each sound component although they used different classification to them.

In this study, Lub-Dub has the highest means duration values to all consistencies tasted and the more intense one, which corroborates that Lub-Dub and SC2 (used by Hammoudi, Hernandez, et al. (2014) could be the same sound component of swallowing. About PC, M and C sound components, they are shorter and appear with low intensity. This could explain why they are sometimes imperceptible by the investigator. Morinière et al. (2006) found a SC3 as an important component of swallowing sounds that seems to be related to Click used in this study, even though no conclusions were done about the origin of the SC3 component.

Considering that Lub-Dub corresponds to Whiteout and assuming it is the moment food moves through the pharynx, we can conclude that this phenomenon has a fairly constant duration in healthy subjects and does not considerably change with consistencies, as well as it was found in other study (Patatas et al., 2011).

About the duration of intervals, the main differences are between the mean duration of saliva and solid to I1, I2 and I3. Two studies showed that mean duration of intervals raise with the increasing of bolus volume (Hammoudi et al., 2014; Patatas et al., 2011). These differences can be justified by methodology used, particularly to mark the swallowing sounds in the waveform.

We confirmed Leslie's findings (Leslie et al., 2007) regarding the sound components: the Preclick seems to be related with the start of epiglottis initial movement (Epistart), and click seems to be linked to the epiglottis movement to the start position (Epireturn), despites the sounds were only present in 18,5% and 39,2% of the cases respectively. To confirm this association it would be necessary to increase the sample size. Whiteout and Lub-Dub have the strongest association, with a percentage of 78,3, as well as Leslie et al. (2007) found in their study, even though they mentioned it was a week association. It would be necessary to realize a similar study using VFSS searching more information about the origin of swallowing sounds. Leslie et al (2007) are currently working on it. Hammoudi et al. (Hammoudi, Hernandez, et al., 2014) confirmed that SC2 is present in all swallowing sounds. This sound component seems to be our Lub-Dub, which are present in 94,2 percent of the cases.

However, not all researches considerer Epiglotis' movement the origin of sound components. Hammoudi et al. (2014) referred SC2 corresponds to the passage of the bolus through SES and SC1 and SC23 ate related to the movement of larynx during swallowing. Morinière et al. (2006) agrees with these results (Hammoudi et al., 2014) and attributed the same causes to origin of sounds. Considering human anatomy and physiology, at this stage the base of the tongue could also have influence in producing the sound.

Irrespective of the sound source, PC and C sound could have the same origin because we found similar durations to both that are different from whiteout duration. We can weight the possibility of the third sound (C) is the anatomical structure returning to its original position. More swallowing sounds would be needed to confirm this hypothesis.

We can conclude that there is no concrete data to accept a specific event and reject other. Two or more events are probably taking place at the same time or happening immediately one after the other Not have been found an objective cause of the produced sound yet, confirming what was said by Leslie et al. (2007).

The most significant difference was observed in the frequency range between 517 and 3617 Hz, values that are different from Taniwaki & Kohyama (2012) which found differences in frequency range of 400-1000Hz (lower frequencies). Few differences could be observed in the variation of swallowing sounds in frequency domain. However, most fluid consistencies seem to produce treble sounds more than solid consistencies.

In the pilot study, dyshagic individual often need more than a single gulp to swallow 10 ml of pudding comparing to healthy subjects. These findings match with previous results (Borr et al., 2007) who reached similar conclusions to liquid consistence. Santamato et al (2009) mentioned that duration of swallowing sounds is longer or shorter in pathological patients than in healthy subjects according to age, and the post-swallowing respiration is changed.

We also found that mean duration of swallowing sounds were significant different between healthy and dysphagic subjects for a 10ml of pudding. Santamato et al. (2009) had found the same results to liquid bolus of 10ml of water. Within the groups we found more disparity results in individuals with dysphagia than in healthy subjects. This disproportion could make sense considering that there are many different causes of dysphagia that may be associated with a specific motor or sensory change. Each perturbation requires different behaviours and adaptations from dysphagic individuals. The phase of swallowing where the perturbation exists could also influence the duration of swallowing process and its sound.

Thorough this work there were found some barriers, which could have influence in the collected and analyses processes and that can be limitations of this study.

One of the limitations is the sample size that was small. They would be needed more healthy subjects and more sounds to compare and to find more statistically results.

The process used to fix the stethoscope on the larynx could also be a disadvantage, because the risk of movement. However, this method seemed to be the best choice comparing with the methods used in previous results. Using own hands, the researcher could control the pressure done in the larynx during the exam and adapt the position of stethoscope in swallowing intervals to try to decrease the influence of this toll making swallowing process less artificial. Besides, stethoscope is fixed in a structure with movement, which seems to produce sound by itself.

It was also observed that the physiology of the individuals has influence producing noise, mainly men with longer bear.

Furthermore, video and audio synchronization was manually performed through calculation. Although researcher had confirmed the results, he may have made some mistakes of a few milliseconds.

The sounds were listened by only a SLP, which could be a bias. Even though he listened sounds more than once, this process depends on his interpretation.

The main drawback with FEED is the period of whiteout because it hides the events that are occurring during pharyngeal stage of swallowing. It also doesn't allow the visualization of some events that could also produce sound such as the upper esophageal sphincter abnormalities, oral stage of swallowing, transit of the bolus, as mentioned by Leslie et al. (2007).

Sounds were also difficult to identify in the waveform and the sounds were selected according to which the investigator listened and graph behaviour. This may had influence the swallowing sounds results as well the duration of sounds components, regardless of using the same method to all recordings to keep consistency in data collection.

12. Conclusion

Cervical Auscultation continues to be used as a technique to complete the clinical evaluation of dysphagia.

This study enables to describe the sounds of a normal swallow, mainly in temporal strcture, and to identify some possible anatomicophysiological events that cause them.

Sounds of swallowing were not easy to identify in the waveform, which make us reflecting about the most adequate method to collect them. Because there is no consensus among researches of what can be considered as the beginning and the end of a swallow, data are still difficult to compare.

Signals behaviour observed in the waveform are very different from each other, but perceptually sounds seem to be more similar. This could corroborate that clinical experience has huge influence in the interpretation of swallowing sounds' information.

Despite some limitations of this study, the results are considered very satisfactory. This research underlines the importance of the swallowing sounds' interpretation in clinical practicing on the assessment and treatment of swallowing disorders. CA could be incorporated into the clinic evaluation, but it should not replace the use of objective diagnostic and valuable measures. There is still no evidence that CA could be independently used.

We can conclude that swallowing sounds contains acoustic characteristics that may allow reliable classification, but further researches are needed to achieve this goal.

12.1. Main findings

In this study three main sounds were identified. The number of sound components observed was different among subjects but also in individual subjects. Lub-Dub, Breath and Click were the most observed sound components. Lub-Dub has the highest means duration values to all consistencies tasted and the more intense one.

It was found different durations between swallowing with and without OTT. Including OTT, we can observe an increase of duration values according to the increase of volume and consistency. If we observe swallowing without OTT, differences in duration were not relevant between bolus consistencies, except to free gulp thin liquid with a higher value. It wasn't found any significant differences in the total duration of swallowing sounds between consistencies and volume of the bolus, except to free thin liquid and 10ml of thin liquid.

PC seems to be related with the start of epiglottis initial movement (Epistart); C seems to be linked to the epiglottis movement to the start position (Epireturn) and Lub-Dub has a strongest association with Whiteout. However, not all researches considerer Epiglotis' movement the origin of sound components. Therefore, we still cannot confirm the origin of swallowing sounds but can accept that a specific sound component is associated with some anatomophysiological event.

We could also conclude that the absence of sound does not necessary indicate abnormalities in swallowing process.

Analysing swallowing sounds in frequency domain, fluid consistencies seem to produce more treble sounds than solid consistencies.

About the pilot study, dyshagic individual often need more than a single gulp to swallow 10 ml of pudding comparing to healthy subjects. We found that mean duration of swallowing sounds were significant different between healthy and dysphagic subjects for a 10ml of pudding.

12.2. Main recommendations

The main recommendation is regard to sample size. More than 30 healthy individuals should be participated to have more statistically significant results.

Furthermore, for the perceptual analyses of swallowing sounds, more than one SLP should be involved to compare personal interpretations and decrease the bias.

Men, who would participate in the study, should be informed to shave after the collecting process of sounds to decrease the noise bear could cause.

13. Future Work

In a future work it would be interesting to collect sounds from the same subject swallowing the same consistency more than once and at different times. Studying individual characteristic of swallowing sounds may be the first step to understand their behavior among healthy subjects. If it has a huge variability in the same person, it would probably be vary between different subjects.

Data base creation of swallowing sounds could be a solution to achieve a huge sample and try to standardize the results. To collect the sounds, a single protocol should be created to decrease differences in methodologies.

In a more challenging long-term perspective, it could be important to study acoustic characteristics in swallowing sounds in dysphagic people to compare with healthy subjects. Challenger would be studying clinical signs of alternations in the biomechanics of swallowing and try to find a association between them and swallowing sounds.

14. References

Aboofazeli, M., & Moussavi, Z. (2006). Analysis of Temporal Pattern of Swallowing Mechanism. *IEEE*, 5591–5594.

Alaska Native Tribal Health Consortium. (2013). Electronic Stethoscopes - Technology Overview | National Telehealth Technology Assessment Resource Center. Retrieved from http://telehealthtechnology.org/toolkits/electronic-stethoscopes/about-electronic-stethoscopes/technology-overview

American Heart Association. (2012). Effects of Stroke. Retrieved January 23, 2016, from http://www.strokeassociation.org/STROKEORG/AboutStroke/EffectsofStroke/Effects-of-Stroke_UCM_308534_SubHomePage.jsp

American Speech-Language-Hearing Association. (n.d.). Swallowing Disorders (Dysphagia) in Adults. Retrieved June 5, 2016, from http://www.asha.org/public/speech/swallowing/Swallowing-Disorders-in-Adults/#what_do

American Speech-Language-Hearing Association. (2004). Role of the Speech-Language Pathologist in the Performance and Interpretation of Endoscopic Evaluation of Swallowing [Guidelines]. *American Speech-Language-Hearing Association*. doi:10.1044/policy.GL2004-00059

Arvedson, J. C., Lazarus, C., Lundy, D. S., Mccullough, G., Newman, L., & Swigert, N. B. (2015). *Roles of Speech-Language Pathologists in Swallowing and Feeding Disorders : Technical Report Dysphagia. American Speech-Language-Hearing Association.*

Balasubramanium, R. K., & Bhat, J. S. (2012). Cervical Auscultation: A Systematic Review, *6*(2004), 1–8.

Bergstrom, L., Svensson, P., & Hartelius, L. (2013). Cervical auscultation as an adjunct to the clinical swallow examination : A comparison with fi bre-optic endoscopic evaluation of swallowing. *Journal of Speech-Language Pathology*, 1–12. doi:10.3109/17549507.2013.855259

Borr, C., Hielscher-Fastabend, M., & Lücking, A. (2007). Reliability and validity of cervical auscultation. *Dysphagia*, *22*(3), 225–234. doi:10.1007/s00455-007-9078-3

Broadley, S., Croser, D., Cottrell, J., Creevy, M., Teo, E., Yiu, D., … Thompson, P. D. (2003). Predictors of prolonged dysphagia following acute stroke - Journal of Clinical Neuroscience. *Journal of Clinical Neuroscience*, *10*(3), 300–305.

Canongia, M., & Alves, C. (2010). *Disfagia - Estudo e reabilitação*. (Revinter, Ed.). Rio de Janeiro.

Cardionics Inc. (n.d.). *The E-Scope® Electronic Stethoscope: CAtalog of Produts*. Texas. Retrieved from http://www.cardionics.com/pdffiles/CatalogE-Scope.pdf

Carvalhido, T., & Pontes, M. (2009). Reabilitação Domiciliária em Pessoas que sofreram um Acidente Vascular Cerebral. *Revista Da Faculdade de Ciências Da Saúde Do Porto*, *6*, 140–150.

Cichero, J., & Murdoch, B. (2006). *Dysphagia: Foundation, Theory and Function*. (John Wiley & Sons Ltd, Ed.). Chichester. Retrieved from http://www.amazon.com/Dysphagia-Foundation-Practice-Julie-Cichero/dp/1861565054

CIES Observatório das Desigualdades. (2012). Europa regista melhorias na saúde, mas a crise económica pode causar retrocessos. Retrieved January 23, 2016, from http://observatorio-das-desigualdades.cies.iscte.pt/index.jsp?page=news&id=233

Cruz-Cunha, M., Miranda, I., Martinho, R., & Rijo, R. (2016). *Encyclopedia of E-Health and Telemedicine*. Hershey PA, USA. doi:10.4018/978-1-4666-9978-6

Direção-Geral da Saúde. (2013). Programa Nacional para as Doenças Cérebro-cardiovasculares. Retrieved from http://www.spc.pt/DL/Home/fm/i019350.pdf

Donovan, N. J., Daniels, S. K., Edmiaston, J., Weinhardt, J., Summers, D., & Mitchell, P. H. (2013). Dysphagia screening: State of the art invitational conference proceeding from the state-of-the-art nursing symposium, international stroke conference 2012. *Stroke*, *44*(4), 24–32. doi:10.1161/STR.0b013e3182877f57

Dudik, J. M., Jestrovi, I., Luan, B., Coyle, J. L., & Sejdi, E. (2015). A comparative analysis of swallowing accelerometry and sounds during saliva swallows. *Dudik et Al. BioMedical Engineering OnLine*, *14*(3), 1–15. Retrieved from http://www.biomedical-engineering-online.com/content/14/1/3

Ekberg, O., Hamdy, S., Woisard, V., Wuttge-Hannig, A., & Ortega, P. (2002). Social and psychological burden of dysphagia: Its impact on diagnosis and treatment. *Dysphagia*, *17*(2), 139–146.

Escoura, J. B. (1998). *Exercícios e manobras facilitadoras no tratamento de disfagias*. Centro de Especialização em Fonoaudiologia Clínica de Motricidade Oral.

Falsetti, P, Acciai, C., Palilla, R., Bosi, M., Carponteri, F., Zingarelli, A. Pedace, C., & Lenzi, L. (2009). Oropharyngeal Dysphagia after Stroke: Incidence, Diagnosis, and Clinical Predictors in Patients Admitted to a Neurorehabilitation Unit. *Journal of Stroke and Cerebrovascular Diseases*, *18*(5), 329–335. doi:http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2009.01.009

Foreman, J. (1990). *Sound Analysis and Noise Control*. (Van Nostrand Reinhold, Ed.). New York. Retrieved from https://books.google.pt/books?id=8-XvBwAAQBAJ&printsec=frontcover&dq=sound+analysis&hl=pt-PT&sa=X&ved=0ahUKEwjckJv6s-zNAhULWxQKHcanBZwQ6AEIKjAC#v=onepage&q=characte&f=false

González-Fernández, M., Ottenstein, L., Atanelov, L., & Christian, A. B. (2013). Dysphagia after stroke: an overview. *Current Physical Medicine and Rehabilitation Reports*, *1*(3), 187–196. doi:10.1007/s40141-013-0017-y

Gray, H. (1985). File:Gray1194.png. In Revised by Warren H. Lewis (Ed.), *Anatomy of the Human Body* (20th ed.). Philadelphia and New York. doi:10.1002/ar.1091360410

Group, T. W. (1998). Development of the World Health Organization WHOQOL-BREF quality of life assessment. The WHOQOL Group. *Psychol Med*, *28*(3), 551–558. doi:10.5.12

Hall, M. J., Levant, S., & DeFrances, C. J. (2012). Hospitalization for stroke in U.S. hospitals, 1989-2009. *NCHS Data Brief*, (95), 1–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22617404

Hammoudi, K., Hernandez, N., Morinière, S., Boiron, M., & Bobiller, C. (2014). Acoustic Study of Pharyngeal Swallowing as a Function of the Volume and Consistency of the Bolus. *Dysphagia*, *29*, 468–474. doi:10.1007/s00455-014-9529-6

Hilamae, K. M. & Palmer, J. B,. (1999). Food transport and bolus formation during complete feeding sequences on foods of different initial consistency. *Dysphagia*, *14*(1), 31–42.

Huang, K.-L., Liu, T.-Y., Huang, Y.-C., Leong, C.-P., Lin, W.-C., & Pong, Y.-P. (2014). Functional outcome in acute stroke patients with oropharyngeal Dysphagia after swallowing therapy. *Journal of Stroke and Cerebrovascular Diseases : The Official Journal of National Stroke Association*, *23*(10), 2547–53. doi:10.1016/j.jstrokecerebrovasdis.2014.05.031

Humbert, I. A., Christopherson, H., & Lokhande, A. (2015). Surface Electrical Stimulation Perturbation Context Determines the Presence of Error Reduction in Swallowing Hyolaryngeal Kinematics. *American Journal of Speech-Language Pathology*, *24*(1), 72. doi:10.1044/2014_AJSLP-14-0045

Jestrovi, I., Dudik, J. M., Luan, B., Coyle, J. L., & Sejdi, E. (2014). Baseline characteristics of cervical auscultation signals during various head maneuvers. *Computers in Biology and Medicine*, *43*(2013), 2014–2020. doi:10.1016/j.compbiomed.2013.10.005

Jotz, G., Angelis, E., & Barros, A. P. (2009). *Tratado da deglutição e disfagia: no adulto e na criança.* (Revinter, Ed.).

Kuo, P., Holloway, R. H., & Nguyen, N. Q. (2012). Current and future techniques in the evaluation of dysphagia. *Journal of Gastroenterology and Hepatology (Australia)*, *27*(5), 873–881. doi:10.1111/j.1440-1746.2012.07097.x

Lee, J., Steele, C. M., & Chau, T. (2011). Artificial Intelligence in Medicine Classification of healthy and abnormal swallows based on accelerometry and nasal airflow signals. *Artificial Intelligence In Medicine*, *52*(1), 17–25. doi:10.1016/j.artmed.2011.03.002

Leng, S., Tan, R. S., Chai, K. T. C., Wang, C., Ghista, D., & Zhong, L. (2015). The electronic stethoscope. *Biomedical Engineering Online*, *14*, 66. doi:10.1186/s12938-015-0056-y

Lenth, R. V. (2006). Java Applets for Power and Sample Size [Computer software]. Retrieved August 10, 2016, from http://homepage.divms.uiowa.edu/~rlenth/Power/

Leslie, P., Drinnan, M. J., Finn, P., Ford, G. A., & Wilson, J. A. (2004). Dysphagla Reliability and Validity of Cervical Auscultation : A Controlled, *240*, 231–240.

Leslie, P., Drinnan, M. J., Zammit-Maempel, I., Coyle, J. L., Ford, G. a, & Wilson, J. a. (2007). Cervical auscultation synchronized with images from endoscopy swallow evaluations. *Dysphagia*, *22*(4), 290–8. doi:10.1007/s00455-007-9084-5

Logeman, A. (1998). *Evaluation and Treatment of Swallowing.* (Austin, Ed.).

Manuscript, A. (2009). Anatomy and physiology of feeding and swallowing - normal and absnormal, *19*(4), 691–707. doi:10.1016/j.pmr.2008.06.001.Anatomy

Martins, M. R. (2005). *Ouvir Fala: Introdução à Fonética do Português*. (Editoral Caminho, Ed.).

Máximo-Esteves, L. (2008). *Visão Panorâmica da Investigação - Acção*. Porto: Porto Editora.

Morinière, S., Beutter, P., & Boiron, M. (2006). Sound component duration of healthy human pharyngoesophageal swallowing: A gender comparison study. *Dysphagia*, *21*(3), 175–182. doi:10.1007/s00455-006-9023-x

Morinière, S., Boiron, M., Alison, D., Makris, P., & Beutter, P. (2008). Origin of the sound components during pharyngeal swallowing in normal subjects. *Dysphagia*, *23*(3), 267–273. doi:10.1007/s00455-007-9134-z

Moussavi, Z. (2005). Assessment of Swallowing SoundsÃ‚Â' Stages with Hidden Markov Model. *IEEE*, 4–7.

Nacci, a, Ursino, F., La Vela, R., Matteucci, F., Mallardi, V., & Fattori, B. (2008). Fiberoptic endoscopic evaluation of swallowing (FEES): proposal for informed consent. *Acta Otorhinolaryngologica Italica : Organo Ufficiale Della Società Italiana Di Otorinolaringologia E Chirurgia Cervico-Facciale*, *28*(4), 206–11. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2644994&tool=pmcentrez&rendertype=abstract

Palmer JB, Hilamae, K. (2003). Eating and breathing: interactions between respiration and feeding on solid food. *Dysphagia Summer*, *18*(3), 169–178.

Palmer, J., Rudin, N., Lara, G., & Crompton, A. (1992). Coordination of mastication and swallowing. *Dysphagia*, *7*(4), 187–200.

Patatas, O. H. G., Gonçalves, M. I. R., Chiari, B. M., & Gielow, I. (2011). Parâmetros de duração dos sinais acústicos da deglutição de indivíduos sem queixa. *Revista Da Sociedade Brasileira de Fonoaudiologia*, *16*(1), 282–290. doi:10.1590/S1516-80342011000300008

Plack, C. J. (2013). The Sense of Hearing: Second Edition. Retrieved from https://books.google.pt/books?id=rCgVAgAAQBAJ&pg=PA100&dq=range+of+hearing&hl=pt-PT&sa=X&ved=0ahUKEwijyo2XuOzNAhXLcRQKHYegAFsQ6AEINTAD#v=onepage&q=%22range of hearing%22&f=false

Rainbow, L. (2001). *Working with dysphagia*. (Speechmark Ed., Ed.).

Ramsey, D. J. C., Smithard, D. G., & Kalra, L. (2003). Early assessments of dysphagia and aspiration risk in acute stroke patients. *Stroke; a Journal of Cerebral Circulation*, *34*(5), 1252–7. doi:10.1161/01.STR.0000066309.06490.B8

Ramsey, D. J. C., Smithard, D. G., Kalra, L., Ramsey, D. J. C., Smithard, D. G., & Kalra, L. (2010). Can Pulse Oximetry or a Bedside Swallowing Assessment Be Used to Detect Aspiration After Stroke ? *Stroke*, *37*, 2984–2988. doi:10.1161/01.STR.0000248758.32627.3b

Richard Lowry. (2001). Confidence Interval of a Proportion. Retrieved from http://vassarstats.net/prop1.html

Santamato, A., Panza, F., Solfrizzi, V., Frisardi, V., Megna, M., Ranieri, M., & Fiore, P. (2009). Acoustic analysis of swallowing sounds: A new technique for assessing dysphagia. *Journal of Rehabilitation Medicine*, *41*(8), 639–645. doi:10.2340/16501977-0384

Santos, R. S., Dacheux, E., & Filho, M. (2006). Sonar Doppler como Instrumento de Avaliação da Deglutição Sonar Doppler as an Instrument of Deglutition Evaluation, 182–191.

Sarraf Shirazi, S., & Moussavi, Z. M. K. (2011). Acoustical modeling of swallowing mechanism. *IEEE Transactions on Bio-Medical Engineering*, *58*(1), 81–7. doi:10.1109/TBME.2010.2080677

Sarraf Shirazi, S., Buchel, C., Daun, R., Lenton, L., & Moussavi, Z. (2012). Detection of swallows with silent aspiration using swallowing and breath sound analysis. *Medical & Biological Engineering & Computing*, *50*(12), 1261–8. doi:10.1007/s11517-012-0958-9

Singh, S. (2006). Dysphagia in stroke patients. *Postgraduate Medical Journal*, *82*(968), 383–391. doi:10.1136/pgmj.2005.043281

Smithard, D. G., Smeeton, N. C., & Wolfe, C. D. a. (2007). Long-term outcome after stroke: Does dysphagia matter? *Age and Ageing*, *36*(1), 90–94. doi:10.1093/ageing/afl149

Soria, F. S., da Silva, R. G., & Furkim, A. M. (2016). Acoustic analysis of oropharyngeal swallowing using Sonar Doppler. *Brazilian Journal of Otorhinolaryngology*, *82*(1), 39–46. doi:10.1016/j.bjorl.2015.12.001

Sousa-Uva, M., & Dias, C. M. (n.d.). _Prevalência de Acidente Vascular Cerebral na população portuguesa: dados da amostra ECOS 2013.

Spaddoto, A., Gatto, A. R., Cola, P. C., Gonçalves, R., Domenis, D. R., & Dantas, R. O. (2012). Components of the acoustic swallowing signal : preliminary. *J Soc Bras Fonoaudiol.*, *24*(3), 218–222.

Stroud, a E., Lawrie, B. W., & Wiles, C. M. (2002). Inter and intra-rater reliability of cervical auscultation to detect aspiration in patients with dysphagia. *Clinical Rehabilitation*, *16*(6), 640–645. doi:10.1191/0269215502cr533oa

Takahashi, K., Groher, M. E., & Michi, K. (1994). Methodology for detecting swallowing sounds. *Dysphagia*, *9*(1), 54–62.

Taniwaki, M., & Kohyama, K. (2012). Fast Fourier transform analysis of sounds made while swallowing various foods. *The Journal of the Acoustical Society of America*, *132*(4), 2478. doi:10.1121/1.4750491

Valim, M. A., Santos, R. S., Dacheux, E., Filho, M., Marcia, E., Regina, M., & Serrato, F. (2007). The Relationship Between the Maximum Time for Fonation , Fundamental Frequency and Protection of the Lower Airways in Patients with Neurological Disfagy. *Intl. Arch. Otorhinolaryngol.*, *11*(3), 260–266.

Vinidh Paleri, & Bradley, P. J. (2012). Evaluation of dysphagia: a contemporary approach. *Jornal Orf ENT Masterclass*, *5*(1), 82–86. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by Subject/1301.0~2012~Main Features~Farming in Australia~207

Yadollahi, A., & Moussavi, Z. (2007). Feature selection for swallowing sounds classification. *Conference Proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology*

Society. Conference, *2007*, 3172–5. doi:10.1109/IEMBS.2007.4353003

15. Appendix

15.1. Appendix 1 - Guideline for Fiberoptic Endoscopic Examinations of Swallowing and Cervical Auscultation exams

1. **Before data collection**

1.1. Prepare consistencies and volumes with blue dye and put them into a cup:

- 5 ml and 10 ml of liquid (water)
- 5ml and 10 ml pudding consistency (with water thickener)
- Solid consistency (Bolacha Maria)

1.2. Turn on the computer and configure Audacity program with the following settings:

- mono line with a 32 bit float resolution at sampling rate of 44,100 Hz.

1.3. Connect the stethoscope to the external sound card without any active filter and then connect it to the computer

1.4. Adjust the volume control of the stethoscope

- it should be 0 at the beginning and then click the button: 4 clicks to men; 10 clicks to women.

1.5. Present the informed consent to the participants and ask them to sign it

2. **During data collection**

Instructions	Done	Not done (comments)
Movement of the tongue base - Produce /kal, kel, kil, kol, kul/		
Movement of the soft palate and uvula - Produce /sa, se, si, so, su/		

Vocal cords adduction - Produce /i/ sustentada		
- Produce /a/ sustentada		
- Count to 10		
Airway protection - Voluntary Cough		
- Throat clearing		
Swallowing liquid (water) - Free gulps		
- 5ml		
- 5ml		
- 10 ml		
- 10 ml		
Swallowing pudding consistency - 5ml		
- 5ml		
- 10ml		
- 10ml		
Swallowing solid consistency - First swallowing		
- Second swallowing		

15.2. Appendix 2 – Query used on the online library PubMed with the following keywords

("Deglutition"[Mesh] OR "swallowing"[All Fields] OR "Deglutition Disorders"[Mesh] OR "Deglutition Disorders/anatomy and histology"[Mesh] OR "Deglutition Disorders/pathology"[Mesh] OR "Deglutition Disorders/physiology"[Mesh] OR "Respiratory Aspiration"[Mesh] OR "laryngeal penetration"[All Fields] OR "post swallow residue"[All Fields] OR "cough"[MeSH]) AND ("sound"[MesH] OR "acoustics"[Mesh] OR "Signal Processing, Computer-Assisted"[Mesh] OR "Wavelet Analysis"[Mesh] OR "Signal Processing, Computer-Assisted"[All Fields] OR "swallowing signal"[All Fields] OR "stethoscopes"[Mesh] OR "Auscultation/methods"[All Fields] OR "digital stethoscope"[All Fields] OR "cervical auscultation"[All Fields] OR "Perception"[Mesh] OR "Pitch Perception"[Mesh] OR "Loudness Perception"[Mesh] OR "Auditory Perception"[Mesh]) AND ("adults"[All Fields] OR "adult"[All Fields] OR "older"[All Fields] OR "aged"[All Fields] OR "dysphagic individuals"[All Fields]) AND ("2006/03/26"[PDAT] : "2016/03/22"[PDAT])