Application of ultrasound method in the evaluation of biomechanical swallowing – literature review

Aplicação do método ultrassonográfico na avaliação da biomecânica da deglutição – revisão de literatura

Aplicación del método de ultrasonido en la evaluación de la biomecánica de la deglución – revisión de literatura

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Abstract

Objective: to verify the application of the ultrasound method in the evaluation of swallowing biomechanics. **Method:** A literature search was conducted on bases Scopus, Science Direct and PubMed, adopting the descriptors, in English: deglutition, healthy subjects, ultrasonography and ultrasonic. The papers were selected without limitation of year, written in Portuguese or English and that focused ultrasound as swallowing assessment method in adults. Only available studies in full text were included. Each paper went through the analysis of titles and abstracts. The following data were extracted: author, country, goal, study sample, evaluation procedure and main results. Ten papers met the inclusion criteria. **Results:** Studies show good applicability of the method in the evaluation of the tongue, hyoid bone, larynx, genius-hyoid muscle and upper esophageal sphincter. **Conclusion:** The ultrasound method has good applicability in the evaluation of swallowing, providing quantitative data and minimizes risk to the patient, avoiding the exposure radiation and use of barium.

Keywords: Deglutition; Deglutition disorders; Health evaluation; Rehabilitation.

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Resumo

Objetivo: analisar aspectos biomecânicos da deglutição pelo método ultrassonográfico por meio de revisão de literatura. Método: Foi realizada pesquisa bibliográfica nas bases SCOPUS, ScienceDirect e PubMed, adotando-se como descritores em inglês: deglutition, healthy subjects, ultrasonography e ultrasonic. Foram selecionados artigos sem limitação de ano escritos em Português ou Inglês que abordassem a ultrassonografia como método de avaliação da deglutição em adultos. Apenas estudos disponíveis na íntegra foram incluídos. Cada artigo passou pela análise de títulos e resumos, sendo posteriormente submetido à avaliação na íntegra. Os seguintes dados foram extraídos: autores, país, objetivo do estudo, amostra, procedimento de avaliação e principais resultados. Dez artigos preencheram os critérios de inclusão. Resultados: os estudos apresentam boa aplicabilidade do método na avaliação da língua, osso hióide, laringe, músculo gênio-hióide e do esfíncter esofágico superior. Conclusão: O método ultrassonográfico apresenta boa aplicabilidade na avaliação da deglutição, fornecendo dados quantitativos e evitando exposição à radiação e uso de bário.

Palavras-chave: Deglutição; Transtornos de deglutição; Avaliação em saúde; Reabilitação.

Resumen

Objetivo: analizar aspectos biomecánicos de la degluticion usando el método de ultrasonido por medio de una revisión de literatura. Metodos: La búsqueda bibliográfica se realizó en las bases Scopus, ScienceDirect y PubMed, adoptando como descritores los términos en Inglés: deglutition, healthy subjects, ultrasonography y ultrasonic. Fueron seleccionados artículos sin limitación de año, escritos en Portugués o Inglés en que el método ultrasonografico fue enfocado como un método de evaluación de la deglución en los adultos. Sólo se incluyeron los estudios disponibles en su totalidad. Cada artículo pasó por análisis de los títulos y de los resúmenes, y posteriormente fue sometido a la evaluación en su totalidad. Los siguientes datos fueron extraídos: autor, país, objetivo del estudio, muestra, procedimiento de evaluación y resultados principales. Diez artículos cumplieron los criterios de inclusión. Resultados: Los estudios muestran buena aplicabilidad del método en la evaluación de la lengua, huesso hioide, laringe, músculo-genio hioide y esfínter esofágico superior. Conclusión: El método de ultrasonido tiene una buena aplicación en la evaluación de la deglución, proporcionando datos cuantitativos y evitando la exposición a la radiación y uso del bario.

Palabras clave: Deglución; Transtornos de deglución; Evaluación en salud; Rehabilitación.

Introduction

Swallowing is a physiological phenomenon that requires the synergetic coordination of several structures, such as the muscles of the mouth, pharynx, larynx and esophagus, which present central and peripheral innervation[1,2], a structure that is responsible for transporting the food from the oral cavity to the stomach, in order to protect both nutritional status and respiratory tract[3].

The swallowing process can be divided into three phases (oral, pharyngeal and esophageal). The oral phase corresponds to chewing and to the formation of a bolus, with subsequent propulsion of the bolus into the pharynx. In the pharyngeal phase there are a number of involuntary events for the protection of the respiratory tract: inversion of the epiglottis over the entrance of the larynx, the anterior-superior displacement of the hyolaryngeal complex, vocal fold closure and opening of the upper esophageal sphincter. The esophageal phase corresponds to the transportation of the bolus until the stomach[1].

Different evaluating methods of the swallowing biomechanics, such as clinical evaluation and complementary instrumental imaging tests, have been proposed in the literature[4]. Among the imaging techniques, the videofluoroscopy of swallowing (VFS), video-endoscopy (VES), ultrasound (US), Doppler sonar and the functional magnetic resonance imaging are the most described.

The VFS is in evidence in the evaluation, being classified as the gold standard, because it is an effective method for analysis of anatomical structures and swallowing physiology, with the possibility of further analysis due to the recording of images, objective measurements with specific software and the possibility of application of different positions. Among the disadvantages, it is possible to mention the exposure to radiation, the use of barium as a

contrast agent and the need for prior training of the examiners to minimize subjectivity[5,6].

Regarding the use of the ultrasound method (US), it has some advantages over other instruments, such as reliability, low cost, absence of ionizing radiation and it is considered a noninvasive method[7,8]. Furthermore, US easily captures the image of soft parts, by means of two display modes: mode-B, which provides two-dimensional image and mode-M, which allows the visualization of the movement through time[9,10].

However, currently, this evaluation method has received little attention in clinical practice and research, although it is confirmed that ultrasound images are presented as a good chance to evaluate the swallowing biomechanics[8].

In this context, the aim of this study is to analyze biomechanical aspects of swallowing with the use of the sonographic method through a literature review.

Methods

For this review, the guidelines of the Cochrane Handbook[11] and the information provided by Sampaio and Mancini[12] were taken into account. The search was performed in the following databases: Scopus, ScienceDirect and PubMed, adopting the following terms in English: deglutition, healthy subjects, ultrasonography and ultrasonic. Associations between them, through the Boolean operator "and", were performed. The bibliographic survey was carried out between April and October 2015.

Studies without the limitation of year of publication were included, in Portuguese or English, which focused ultrasound as an evaluating method of swallowing in adults.

Opinion of experts, theses, dissertations, monographs, studies that were about diseases and/or disorders (tongue, palate, pharynx, larynx), evaluation of dysphagic subjects of any etiology, experimental models, esophageal swallowing, only children, medications, epidemiological data, other languages and that were not available in their entirety were excluded from the analysis.

Initially, each work that was found passed through the evaluation of titles and abstracts and, if they were of interest, it started the search for relevant articles in full availability. At the end, 10 articles were included in this review; from these ones the following data were extracted: author, country, aim of the study, sample, evaluation procedure and main results, which were included in the descriptive summary in Figure 2.

Resultados

Figure 1 shows the flowchart of search and selection of the studies.

The meta-analysis was not possible due to the heterogeneity of the studies, to the evaluated structures and to the modes of application of US.

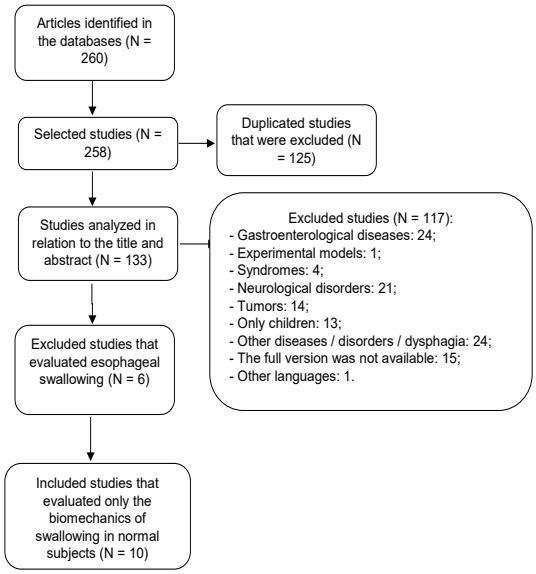

Figure 1. Flowchart of the search of the articles in the Scopus, ScienceDirect and PUBMED databases

By means of these studies, it was observed that the first publications occurred after 1994[13]. About the countries where the research was carried out, 30% of the studies occurred in Japan, 20% in Italy and 20% in Taiwan. The other countries were France (10%), Canada (10%) and England (10%). It could be also noted that 60% of the articles were published in the last 10 years (2006-2013).

Regarding the studied samples, there is a variation in the number of subjects (minimum eight and maximum 60) and age (minimum 20 and maximum 79 years). One study included newborns and adults approaching reference points for evaluation of swallowing with the US, thus it was decided to include it in the review and analysis of data.

In Figure 2, it is presented the descriptive summary of the selected studies.

Figure 2. Descriptive summary of the studies.

AUTHORS (YEAR)	COUNTRY	AIM	SAMPLE	EVALUATION PROCEDURE	MAIN RESULTS
Komori et al. (2008)[14]	Japan	Comparing the combined techniques of VES, US and VFS in healthy subjects	8 healthy subjects (from 25 to 31 years old)	VES (flexible endoscope), US (transducer positioned vertically beside the neck, so that the movement of the thyroid cartilage could be observed in each swallow) and VDS (system of subtraction digital angiography) were performed simultaneously when the subject swallowed 15 ml of barium	The movement and the length of the laryngeal elevation measured by US and VDS were approximately the same and significantly correlated (p <0.0001)
Peng et al. (2007)[15]	Taiwan	Evaluating the movements of tongue during swallowing	55 healthy subjects	The transducer of US was positioned in the submental region on the medial plane of the head so that the sound wave was performed in the frontal plane perpendicularly through the frontonasal suture. The records occurred simultaneously in the modes B and M, swallowing 3-5 ml of water	The mode -M provides better image of the tongue. The amplitude, length and standard of movements differ between subjects but intra-individually they were well reproduced
Wijk et al. (2006)[16]	England	Quantifying the oral movements, especially the tongue, in the processing of semi-solid food (sweet, sour, creamy and thick)	8 healthy subjects	Each subject swallowed 5 ml (teaspoon) of each food with different viscosities. US was used in the mode-B (5 MHz) below the chin (submental area), so as to allow a sagittal section of the floor of the mouth.	There was a significant difference between the thickness of each food (p <0.05) and for the most viscous ones there was higher oral transit time (p <0.05).
Fanucci et al. (1994)[13]	Italy	Identify echographic reference points for the evaluation of the oral phase of swallowing	40 healthy adults 20 healthy newborns	It was requested that each adult swallow 20 ml of water; for newborns the evaluation was carried out during the suction of the bottle. Initially transverse scans of the neck were obtained to evaluate laryngeal mobility with a convex transducer of 7.5 MHz; the oral cavity was evaluated using sagittal and coronal scans through submental acoustic window with a transducer of 5 MHz	The positioning of the transducer below the thyroid allows full visualization of the larynx; in the submental region the US provides anatomy images of the tongue and around the floor of the mouth clearly. These points serve as reference for adults and newborns.

Yabunaka et al. (2011)[7]	Japan	Evaluating the movement of the hyoid bone during swallowing in elderly subjects with the use of US	30 healthy subjects were divided into three groups according to age (20-39, 40-59, 60-79 years old)	The transducer of US was positioned in longitudinal section above the larynx; each subject swallowed 5 ml of water; the movement of the hyoid was divided into the stages of elevation, anteriorization, pause and return to regular position	There was a significant difference in total time of swallowing between groups ($p < 0.05$), being higher in the elderly group (60-79 years); the elevation and the pause were significantly lower in the elderly when compared to younger subjects (20-39 years) ($0 < 0.05$)
Casas et al. (2002)[17]	Canada	Evaluating the oral phase of swallowing of four different liquids in relation to the image (brightness) and the ease of identification of fluid intake during the evaluation with US	10 healthy adults (from 21 to 31 years old)	Seven professionals (two speech therapists, two radiologists and three pediatric dentists) evaluated the images of the oral swallowing of four different liquids (carbonated cola, 5 ml of thickener in 120 ml of water, 2.5 ml of water in 120 ml of water and 7.5 ml of icing sugar in 120 ml water); images were obtained by positioning the transducer (3.5 MHz) in the submental region; intra concordance analysis and inter-rater was applied.	Only carbonated cola beverage had higher bright compared with water ($p = 0.01$); while in the analysis of agreement (k) only cola beverage (moderate inter-rater $k = 0.50$) and 5 ml of water in thickener ((poor inter-rater $k = 0.24$) were better visualized in the ultrasound images
Yabunaka et al. (2012)[18]	Japan	Investigating the application of the mode B-M mode in the US image as a new approach to quantify the activity pattern (mobility and contraction time) of the genius-hyoid during swallowing and evaluating how this standard differs in relation to age and gender	60 healthy subjects (30 men, 30 women) were divided into three groups according to age (20-39, 40-59, 60-79 years old)	All subjects drank 10 ml of water; the images of US were obtained simultaneously in modes B-M along the lateral muscular wall of the genius-hyoid	Mobility and genius-hyoid contraction time gradually increased with age, but with no significant difference; in relation to gender, both the mobility and the contraction time, differed significantly in three age groups (20-39 $p = 0.009$; $p = 0.035$ 40-59; 60-79 $p = 0.018$)
Fanucci et al. (1997)[16]	Italy	Evaluating the presence of multiple swallows in healthy subjects	22 healthy subjects (from 21 to 62 years old)	All subjects were evaluated with a transducer of 5 MHz (M-mode) positioned in the submental region with visible hyoid bone (the full swallowing was inferred by the bone back to its original position); each subject swallowed 5 and 10 ml of water and 10 g of semi-solid food (cookie inside coffee)	Multiple swallows were found in 41% of subjects; in relation to the volume and consistency, there were multiple swallows - 18% with 5 ml, 36% with 10 ml and 60% with semi solid

Peng et al. (2000)[19]	Taiwan	The aims were to introduce the sonographic technique (mode-M) in the area of dental research and to determine if it could be used to measure the language functions during swallowing	25 healthy subjects (from 8 to 50 years old)	Swallowing was investigated in mode-B and in mode-N, with the transducer positioned between the rear edge of the symphysis and the anterior margin of the hyoid bone, mid-sagittal plane. At the same time, the transducer was guided with its long axis perpendicular to the Frankfort horizontal plane; all participants swallowed 3 to 5 ml of water, with a 10 second interval, then they only swallowed saliva	The mean time of swallowing for the subjects was 2.43 ± 0.62 s and the phase IIIb of the tongue was the longest (mean of 0.91 s); in relation to the movement of phase IIa, which showed higher displacement (mean of 10.73 mm)
Morinière et al. (2013)[20]	France	Developing a methodology and standard tools for studying the upper esophageal sphincter during swallowing.	25 healthy subjects (15 women and 10 men, from 20 to 56 years old)	US was performed with a transducer of 7 MHz, obtaining axial view along the lower edge of the cricoid cartilage, identified by palpation and the US image; the upper esophageal sphincter was recognized for its anatomical structure in a specific form of C which comes with the cricoid cartilage; the subjects were instructed to swallow 10 ml of water (offered in syringe)	The mean diameter of the sphincter closed was 0.78 ± 0.13 cm, while the mean opening time was 415 ± 57.66 ms and the mean travel time was 937 ± 120.98 ms. Maximum anterior and lateral displacement was 0.42 ± 0.12 cm and 0.35 ± 0.18 cm, respectively; there was a significant difference between men and women in relation to the lateral displacement of the sphincter (p = 0.04)

US – ultrasound; VDS – videofluoroscopy; VES – videoendoscopy.

Discussion

Swallowing is a dynamic and complex neuromuscular process that has the function of both transporting the bolus from the oral cavity to the stomach and ensuring the protection of the respiratory tract against the aspiration and, therefore, it can be affected by several neurological and systemic diseases. It may also be influenced by the effects of aging[21].

The selected studies presented a very large variation in terms of age, being included newborns, children, young adults, adults and elderly people. It could be seen samples with ages ranging from few days to 79 years [7,14-16,19].

It is noteworthy that the natural process of aging causes morphological and physiological changes, being multifactorial and heterogeneous, with decreased behavioral and neural plasticity[22]. Thus, changes in the swallowing function may be present in older subjects[23].

In this regard, it is highlighted the need for homogeneous studies on the age factor, since the evaluation findings can be influenced by the heterogeneity of the sample.

The use of US has been performed as an evaluation method and quantification of parameters of the swallowing biomechanics, being an important tool with many advantages such as: allowing evaluation to the bedside, not being invasive, no radiation exposure, not using contrast and low cost[7,13,18]. In addition, soft parts allow the visualization and the quantification of the movements of the muscles involved in swallowing[19].

Then, the choice of the US mode and the anatomical region that the equipment will be positioned are essential for achieving the proper results, being the mode B and M the most used modes[18].

The research of Fanucci et al.[13] analyzed the structures that are associated with the swallowing in infants, children and adults with the US method. The authors were able to better identify the structures and movements that are performed during the oral and pharyngeal phases in adults, because the size and proximity of structures in newborns and children impaired the identification. However, the researchers also evidenced that US may be used in this age group, and that it is a method with no exposure to radiation, so it can be used during breastfeeding, allowing the individual evaluation of the exact position of the nipple inside the mouth of the baby, coordination of the rhythm of sucking and swallowing.

The work of Peng et al.[19] tried to determine the use of US in order to measure the tongue functions during swallowing. This work found that the mean time of swallowing was 2.43 seconds and that the tongue moved differently in its anterior third, medium and posterior during swallowing. The study of Peng et al.[15] evaluated tongue movements during swallowing by checking that US, in mode M, provides valid information on the tongue movement, being then a useful tool for research on the tongue function. Wijk et al.[9] used US to quantify the tongue movements during the chewing of food of different consistencies.

The results showed that the tongue movements are related to food properties, such as taste and viscosity, since for the most solid foods there was the need of higher strength and precision of the tongue movements, being the method a good analytical tool of tongue during the oral phase of swallowing.

Yabunaka et al.[7] analyzed the movement of the hyoid bone through US and the age-related changes during swallowing in healthy subjects. The investigators described four phases of movement of the hyoid, namely: increase bone from the rest position, anteriorization, maintenance of high and forward position and return to the rest position. It was also evident that the observed path was similar to the one found in VFS.

The work of Komori et al.[14] used the evaluation methods: video-endoscopy (VE), videofluoroscopy (VFS) and ultrasonography (US) to compare these methods and to evaluate quantitatively some aspects related to the biomechanics of swallowing in healthy subjects. The study found similar values of laryngeal elevation and support of the high larynx in the VFS and US examinations, being the findings considered statistically significant.

Yabunaka et al.[18] investigated the application of US (mode B and M) for quantifying the displacement of the genius-hyoid muscle during swallowing in subjects of both genders and age groups. The authors found that the mean muscle contraction gradually reduced with age, being statistically significant for men, being it justified by the loss of muscle strength with age. Thus, the method used, since it allows the analysis of soft tissues, seems to be a good ally in the evaluation of some muscles that are involved in swallowing.

Morinière et al.[20] used US to quantify the opening of the upper esophageal sphincter (UES) during swallowing in healthy subjects. The authors characterized the mean time of opening of UES, the time of displacement and the return to the rest position. They concluded that the use of US allowed the description and measurement of the anterolateral displacement of UES during swallowing.

The research of Casas et al.[17] investigated, among four types of liquid, which one presented greater ease of identification for the US examination of the swallowing, verifying that only a cola beverage showed a higher level of brightness than water (used as a control).

Fanucci et al.[16] evaluated the swallowing of 22 normal subjects, with the use of US, in order to check the occurrence of multiple swallows in this population. The results were against the results found in other studies with VFS, which demonstrate that multiple swallows occur with liquid in 41% of the subjects.

Thus, the use of US can be effective for the investigation on the biomechanics of swallowing, with parameters similar to those ones found for VFS, and it can enable the evaluation to be performed in a hospital bed, not being necessary to move patients to the service of radiology and avoiding the exposure to radiation.

Until now, studies that verified the sensitivity and specificity of US as an evaluation method of the biomechanics of swallowing were not found in literature.

Conclusion

Through this review, it is possible to verify that the ultrasound method allows a quantitative evaluation of the biomechanics of swallowing, without offering risks to patients, such as exposure

to radiation and the use of barium, as it occurs in VFS.

Among the structures related to the biomechanics of swallowing, possible to be evaluated by the method demonstrated by the review, we highlight the tongue, hyoid bone, larynx, genius-hyoid muscle and UES.

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