

Physiological mechanisms and pulmonary protection strategies in aspiration: implications for speech-language pathology practice

Mecanismos fisiológicos e estratégias de proteção pulmonar na broncoaspiração: implicações para a prática fonoaudiológica

Mecanismos fisiológicos y estrategias de protección pulmonar en la broncoaspiración: implicaciones para la práctica fonoaudiológica

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Abstract

Bronchoaspiration represents one of the main adverse outcomes in individuals with dysphagia, being associated with aspiration pneumonia, prolonged hospitalization, the need for ventilatory support, and increased mortality. Despite its relevance, Speech-Language Pathology still tends to approach aspiration predominantly as a dichotomous pathological event, rather than as a biological process regulated by intrinsic pulmonary defense mechanisms. The purpose of this text is to provide an updated and integrated description of the main physiological mechanisms involved in pulmonary protection—particularly cough, mucociliary clearance, the innate alveolar immune response, the role of pneumocytes, the lymphatic system, and microbial homeostasis—and to contextualize them in relation to bronchoaspiration and speech-language pathology practice. We discuss the implications of these mechanisms for the assessment, prognosis, and clinical management of dysphagia, emphasizing that treating swallowing disorders alone is not always sufficient to prevent aspiration pneumonia and other respiratory comorbidities. The text advocates for a broadened perspective that incorporates multiprofessional pulmonary protection strategies, including respiratory muscle training, airway clearance techniques, positive expiratory pressure devices,

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intensive oral hygiene, functional monitoring, and health education. Understanding these mechanisms should guide clinical practice, curriculum design, and future research, bringing Speech-Language Pathology closer to respiratory physiology and pulmonary immunology.

Keywords: Respiratory Aspiration; Immunity; Pneumonia, Aspiration; Deglutition Disorders; Speech-Language Pathology;

Resumo

A broncoaspiração representa um dos principais desfechos negativos em indivíduos com disfagia, associando-se a pneumonias aspirativas, aumento de tempo de internação, necessidade de suporte ventilatório e mortalidade. Apesar dessa relevância, a Fonoaudiologia ainda tende a abordar a aspiração predominantemente como um evento patológico dicotômico, e não como um processo biológico, regulado por mecanismos próprios de defesa pulmonar. Este texto tem como objetivo descrever, de forma atualizada e integrada, os principais mecanismos fisiológicos envolvidos na proteção pulmonar, em especial a tosse, a depuração mucociliar, a resposta imune inata alveolar, o papel dos pneumócitos, do sistema linfático e da homeostase microbiana, e contextualizá-los à broncoaspiração e à prática fonoaudiológica. Abordamos as implicações desses mecanismos para a avaliação, o prognóstico e o manejo clínico da disfagia, enfatizando que o tratamento exclusivo das alterações de deglutição nem sempre é suficiente para prevenir pneumonias aspirativas e outras comorbidades respiratórias. Defende-se uma visão ampliada que incorpore estratégias multiprofissionais de proteção pulmonar, incluindo treinamento muscular respiratório, técnicas de depuração, dispositivos de pressão expiratória positiva, higiene oral intensiva, monitoramento funcional e educação em saúde. A compreensão desses mecanismos deve orientar práticas clínicas, organização curricular e novas pesquisas, aproximando a Fonoaudiologia da fisiologia respiratória e da imunologia pulmonar.

Palavras-chave: Aspiração Respiratória; Imunidade; Pneumonia Aspirativa; Transtornos de Deglutição; Fonoaudiologia;

Resumen

La broncoaspiración representa uno de los principales desenlaces negativos en individuos con disfagia, asociándose con neumonías aspirativas, mayor tiempo de hospitalización, necesidad de soporte ventilatorio y mortalidad. A pesar de esta relevancia, la Fonoaudiología aún tiende a abordar la aspiración predominantemente como un evento patológico dicotómico, y no como un proceso biológico regulado por mecanismos propios de defensa pulmonar. El objetivo de este texto es describir, de manera actualizada e integrada, los principales mecanismos fisiológicos involucrados en la protección pulmonar, en especial la tos, la depuración mucociliar, la respuesta inmune innata alveolar, el papel de los neumocitos, del sistema linfático y de la homeostasis microbiana, y contextualizarlos en relación con la broncoaspiración y la práctica fonoaudiológica. Abordamos las implicaciones de estos mecanismos para la evaluación, el pronóstico y el manejo clínico de la disfagia, enfatizando que el tratamiento exclusivo de las alteraciones deglutorias no siempre es suficiente para prevenir las neumonías aspirativas y otras comorbilidades respiratorias. Se defiende una visión ampliada que incorpore estrategias multiprofesionales de protección pulmonar, incluyendo entrenamiento muscular respiratorio, técnicas de depuración, dispositivos de presión expiratoria positiva, higiene oral intensiva, monitoreo funcional y educación en salud. La comprensión de estos mecanismos debe orientar las prácticas clínicas, la organización curricular y nuevas investigaciones, acercando la Fonoaudiología a la fisiología respiratoria y a la inmunología pulmonar.

Palabras clave: Aspiración Respiratoria; Inmunidad; Neumonía por Aspiración; Trastornos de Deglución; Patología del Habla y Lenguaje;



Introduction

Aspiration is defined as the entry of solid or liquid material into the lower airways and may lead to outcomes ranging from mild, self-limited symptoms to acute respiratory failure and death within minutes, depending on the volume aspirated, the nature of the material, and the individual's clinical condition^{1,2}. In individuals with dysphagia, particularly older adults, people with neurological disorders, and critically ill patients, pulmonary aspiration is frequent and underdiagnosed, with a substantial impact on morbidity, mortality, and healthcare costs¹.

Traditionally, Speech-Language Pathology has approached aspiration primarily from the perspective of oropharyngeal dysphagia, with emphasis on preventing food, liquids, or saliva from entering the airway. Although this perspective is essential, it does not fully capture the complexity of aspiration. Recent literature has proposed a broader understanding of aspiration as a biological process that may at times be unavoidable and remains insufficiently explored, in which the body relies on multiple physiological defense strategies to recognize, contain, clear, and respond to foreign material reaching the lower respiratory tract¹.

Within this context, pulmonologists and respiratory physiotherapists have historically led the body of knowledge on pulmonary physiology, secretion clearance, innate immunity, and protection of the bronchial tree. Speech-Language Pathology, in contrast, has not yet systematically incorporated these concepts into professional training, clinical practice, and research. In many cases, clinical reasoning is limited to the presence or absence of aspiration on instrumental assessment, without adequately integrating cough effectiveness, the integrity of mucociliary clearance, local immune response, and the patient's overall pulmonary defense status¹⁻⁷.

Silent aspiration illustrates this challenge. Even in the absence of cough, part of the aspirated material may be handled by physiological defense mechanisms; conversely, seemingly small volumes may precipitate pneumonia that is difficult to control^{2,8}. This variability suggests that pulmonary aspiration alone does not sufficiently explain clinical outcomes in patients with dysphagia. Other factors must also be considered, particularly the

functional status and reserve of pulmonary defense mechanisms¹.

Accordingly, the aim of this article is to provide an updated and integrated description of the main physiological mechanisms involved in pulmonary protection and to contextualize them within aspiration and speech-language pathology practice. We seek to encourage a broader perspective that acknowledges respiratory complexity and recognizes that dysphagia treatment alone is not always sufficient to prevent aspiration pneumonia and related comorbidities. Understanding pulmonary defense mechanisms should inform clinical practice, curriculum development, multiprofessional strategies, and future research in Speech-Language Pathology and Dysphagia as an interdisciplinary field. To date, no studies specifically addressing this perspective have been identified.

Description

Cough

Cough is the most widely recognized and extensively studied pulmonary defense mechanism. It is a complex reflex that generates high airflow capable of removing mucus, secretions, and particles from the larynx, trachea, and main bronchi³. It is classically described as comprising three coordinated phases: inspiratory, compressive, and expulsive. During the inspiratory phase, a relatively large inspiratory volume is generated, followed by glottic closure and vigorous contraction of the expiratory muscles during the compressive phase, leading to a marked increase in intrathoracic pressure. Sudden glottic opening during the expulsive phase produces high-pressure, high-velocity airflow, promoting shear forces and secretion displacement³⁻⁵.

In healthy individuals, intrathoracic pressure may exceed 300 mmHg, and peak expiratory flow may reach velocities of several hundred kilometers per hour^{4,5}. Effective cough depends on an intact reflex arc, including receptors, afferent pathways, central integration, and efferent pathways, as well as adequate respiratory muscle strength and patent airways. In the general population, the prevalence of chronic cough ranges from 5% to 40%, influenced by environmental exposure, smoking, chronic respiratory disease, and occupational risk factors^{5,6}.

In speech-language pathology practice, reports of coughing during or after meals are clinically



useful for identifying aspiration risk. However, instrumental examinations such as videofluoroscopic swallowing study and flexible endoscopic evaluation of swallowing remain more sensitive and specific for detecting aspiration, particularly silent aspiration^{2,7}. Even so, qualitative assessment of cough, including its presence, its temporal relationship to swallowing, intensity, productive or nonproductive character, and the ability to generate repeated sequential coughs, contributes to prognostic reasoning and to decision-making regarding feeding safety, diet prescription, and the need for protective interventions^{8,9}.

In frail individuals and in those with neurological disorders or generalized weakness, the cough reflex may be diminished, absent, or ineffective, thereby increasing the risk of silent aspiration and pulmonary complications². It is essential to distinguish cough triggered by laryngeal penetration or aspiration from cough associated with respiratory infection, environmental irritants, or bronchospasm, since these conditions may coexist and complicate clinical interpretation^{2,4,5}.

Traditional speech-language pathology maneuvers, such as supraglottic and super-supraglottic swallow, use deliberate cough after swallowing as a laryngeal clearance strategy, thereby reducing residue and minimizing the volume of material that may reach the airway⁹. Volitional cough training and, in selected cases, assisted cough training performed in collaboration with physiotherapy may be critical for patients with dysphagia and limited respiratory reserve¹⁰⁻¹². It should also be emphasized that cough acts predominantly in the proximal airways and medium-caliber bronchioles. Because the alveoli lack contractile smooth muscle and receptors capable of triggering this reflex, they depend on other clearance and immune mechanisms^{6,10,11}.

Cilia and mucociliary clearance

Mucociliary clearance (MCC) is considered the first line of defense in the conducting airways. This mechanism depends on the coordinated interaction among ciliated epithelium, the periciliary layer, and mucus, which together trap and transport inhaled particles, cellular debris, microorganisms, and microaspirated material toward the oropharynx^{6,11}. Effective function of this system requires preserved ciliary structure, coordinated ciliary

beating, appropriate mucus viscosity and elasticity, and adequate hydration of the bronchial surface⁶.

Impairment of MCC is common in respiratory infections, smoking, dehydration, exposure to pollutants, and primary ciliary disorders, reducing mucus transport efficiency and increasing the risk of microbial colonization and inflammation^{6,10}. In patients with dysphagia, continuous aspiration of colonized saliva, oropharyngeal secretions, and small amounts of food material may overload this system, rendering it insufficient and predisposing patients to recurrent infection and bronchopneumonia^{1,6,10}.

Speech-Language Pathology may contribute indirectly to optimizing MCC by encouraging adequate hydration, supporting respiratory organization during eating and speaking, providing postural guidance, and promoting global mobility in bedridden patients^{1,9,12}. Within multiprofessional care, positive expiratory pressure (PEP) and oscillatory positive expiratory pressure (OPEP) devices, including EPAP with a PEEP valve, Threshold®, Shaker®, Flutter®, Acapella®, and Aerobika®, assist in secretion mobilization, improve mucociliary transport, and help prevent atelectasis¹²⁻¹⁸. Although these devices are often prescribed by physiotherapists, speech-language pathologists specializing in dysphagia should understand their anatomical and physiological basis, therapeutic objectives, and potential interfaces with swallowing and voice.

Alveolar macrophages and innate immune response

In the alveoli, the principal line of defense is provided by alveolar macrophages, which phagocytose microorganisms, aspirated particles, and apoptotic cells while also modulating the local inflammatory response^{10,11}. These cells identify pathogens through pattern-recognition receptors, produce proinflammatory and anti-inflammatory cytokines, and coordinate the activation of other immune cells, thereby contributing either to resolution of inflammation or, when dysregulated, to its persistence^{10,11}.

Chronic and repeated activation of macrophages, as occurs in recurrent aspiration, may lead to persistent inflammation, tissue remodeling, fibrosis, and impaired pulmonary function^{1,10,11}. In older adults, immunosuppressed individuals, and patients with preexisting pulmonary disease, this immune



reserve is diminished, so that even relatively small-volume microaspiration may have major clinical consequences^{1, 10}. In these circumstances, speech-language pathology intervention should focus on reducing the frequency and volume of aspirated material and optimizing oral hygiene, while close multiprofessional collaboration with pulmonology, dentistry, and physiotherapy is essential to prevent overload of the pulmonary immune system^{1, 13}.

From this perspective, when dysphagia with aspiration risk or observed aspiration is identified on clinical and/or instrumental assessment by a speech-language pathologist specializing in dysphagia, referral to a pulmonologist should be considered necessary.

Type I and type II pneumocytes and surfactant

Type I and type II pneumocytes line the alveolar surface and play key roles in pulmonary homeostasis. Type I pneumocytes are thin cells primarily responsible for gas exchange, whereas type II pneumocytes produce pulmonary surfactant, a substance essential for reducing surface tension, preventing alveolar collapse, and maintaining alveolar mechanical stability^{10, 11}.

Beyond their mechanical role, type I and type II pneumocytes also participate in innate immunity by recognizing pathogens, modulating inflammatory responses, and interacting with alveolar macrophages and other inflammatory cells^{10, 11}. Patients with chronic aspiration, systemic disease, prolonged mechanical ventilation, or exposure to toxic agents may develop progressive structural injury to these cells, resulting in increased alveolar permeability, edema, inflammation, and respiratory dysfunction^{1, 10}. Preventing aspiration whenever possible, or at least reducing the volume and frequency of microaspiration, is therefore essential for preserving pneumocyte integrity and surfactant function.

Pulmonary lymphatic system

The pulmonary lymphatic system is responsible for drainage of interstitial fluid, removal of cellular debris, and transport of immune cells and antigens^{10, 11}. In chronic aspiration, recurrent infection, or persistent inflammation, lymphatic overload may impair immune clearance, facilitate dissemination of pathogenic agents, and contribute to edema and altered lung compliance^{6, 10, 11}.

For the multiprofessional team, strategies such as appropriate positioning, early mobilization, respiratory training, and clearance techniques may indirectly support lymphatic function by reducing fluid accumulation and facilitating resolution of inflammatory processes^{16, 17}. Pharmacological treatment alone is often insufficient to fully restore pulmonary drainage function; for this reason, an integrated multiprofessional approach is indispensable^{10, 11}.

Microbiota, pH, and pulmonary homeostasis

The pulmonary microenvironment is regulated by a complex interaction among the microbiota, pH, which is slightly acidic, epithelial barriers, and biochemical defense mechanisms. Under physiological conditions, the lungs maintain a low microbial burden and a chemical balance that favors immune tolerance and rapid resolution of injury^{6, 10, 11}.

Disruption of this environment, whether due to infection, repeated antibiotic exposure, dehydration, chronic disease, or persistent aspiration of colonized material, promotes dysbiosis, chronic inflammation, and increased susceptibility to pneumonia^{1, 13}. Rigorous oral hygiene, adequate hydration, control of dental biofilm, management of gastroesophageal reflux, and dietary modification all play an important role in maintaining homeostasis and preventing aspiration pneumonia^{1, 9, 13}. Multiple coordinated strategies may therefore help reduce the impact of oropharyngeal colonization on the respiratory tract.

Speech-language pathology strategies for pulmonary protection

Speech-language pathology management of dysphagia should incorporate techniques that support pulmonary clearance and protection, recognizing that aspiration cannot always be completely eliminated but may, in some cases, be managed or compensated for^{1, 2, 12}. The main available strategies include the following.

- **LaxVox and OPEP devices:** These generate oscillatory positive expiratory pressure, thereby facilitating mobilization of secretions in the middle and upper airways. When combined with physician-prescribed nebulization and ap-

appropriate hydration management guided by the nutritionist, they may improve mucosal hydration and facilitate mucociliary clearance^{12, 14–16, 18}.

- **Respiratory muscle training:** This intervention increases maximal expiratory pressure, improves cough effectiveness, and may be carried out collaboratively by speech-language pathologists and respiratory physiotherapists^{12, 16, 19}.
- **Volitional and assisted cough training:** This approach is particularly important for patients with dysphagia who present muscle weakness or impaired coordination, as it contributes to a more effective cough pattern and improved secretion management^{9, 16, 17}.
- **Airway protection maneuvers:** Maneuvers such as supraglottic and super-supraglottic swallow involve voluntary airway closure, protective breath-holding, and deliberate post-swallow cough, thereby reducing the volume of material remaining in the larynx and trachea⁹. In some cases, isolated cough after specific swallows may also be indicated as a clearing strategy, as may throat clearing and expectoration.
- **Peak flow monitoring:** Measurement of peak expiratory flow may assist in monitoring expiratory strength and cough capacity. It may also serve as a biofeedback tool, improving the patient's perception of airflow limitation and engagement in rehabilitation programs^{12, 17, 19}.
- **Intensive oral hygiene and dental biofilm control:** These measures are essential to reduce the aspirated microbial burden, particularly in older adults, bedridden patients, and individuals with dental prostheses or significant biofilm accumulation^{1, 13}.
- **Health education and multiprofessional coordination:** Pulmonary protection in dysphagic patients requires integrated action involving pulmonology, physiotherapy, nursing, dentistry, nutrition, and family medicine, both in hospital settings and in primary care^{1, 8, 11, 16}.

These strategies do not replace dysphagia management; rather, they complement it by broadening the focus of care from the oropharynx to the respiratory system and the patient's overall health. The specialist speech-language pathologist must understand the integrated functioning of pulmonary defense mechanisms in order to design safe interventions grounded in each patient's physiological condition.

Systematic incorporation of content on pulmonary aspiration, physiological defense mechanisms, and respiratory protection strategies into academic curricula, residency training, and continuing education programs may strengthen preparation of speech-language pathologists to work with complex patients across hospitals, primary care, home rehabilitation, and long-term care settings.

Final considerations

Pulmonary defense mechanisms act in an integrated manner to protect the respiratory system against aspiration. Speech-language pathologists specializing in dysphagia must understand this system and its interactions in order to ensure safe dysphagia management, prevent respiratory complications, and contribute to more effective multiprofessional practice.

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