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Review Article

Impact of High-Flow Nasal Cannula and Non-Invasive Ventilation on Swallowing Physiology: A Literature Review

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ABSTRACT

Deglutition requires adequate coordination between breathing and swallowing. In the clinical context, the use of non-invasive ventilatory devices such as high-flow nasal cannulas (HFNC) or non-invasive ventilation (NIV) has become highly relevant in recent years. However, there is little information regarding how these devices could interfere with the physiology of deglutition. This study aimed to describe the impact of HFNC and NIV on swallowing physiology. To this end, a literature review was carried out using PubMed, Medline, Embase, Web of Science, Lilacs, and Scielo. Studies performed on populations ≥18 years old where HFNC or NIV were used were included. Studies where the population had a history of dysphagia, need for intubation, and presented neurological, neuromuscular, or respiratory diseases, among others, were excluded. The results show that HFNC could decrease the swallowing rate (with flows ≥ 20 L/min; $p<.05$), decrease the mean activation time of the swallowing reflex in proportion to the flow ($p<.05$), increase the risk of aspiration when using higher flows (>40 L/min, $p<0.05$), and increase the average duration of the laryngeal vestibule closure ($p<.001$). NIV, particularly BiPAP, could increase the risk of aspiration due to the higher rate of post-swallowing inspiration (SW-I, $p<.01$). Although the evidence available on this matter is limited, these results offer relevant information that should be considered when working with patients who use these ventilatory devices. Further research should be carried out to strengthen the evidence that is provided in this study.

Keywords:
Swallowing; Swallowing Disorders; Non-Invasive Ventilation; High Flow Nasal Cannula

Impacto de la cánula nasal de alto flujo y la ventilación no invasiva en la fisiología deglutoria: revisión de la literatura

RESUMEN

El proceso deglutorio requiere de una adecuada coordinación entre respiración y deglución. En el contexto clínico, el uso de dispositivos ventilatorios no invasivos, como la cánula nasal de alto flujo (CNAF) o la ventilación no invasiva (VNI), ha cobrado gran relevancia durante los últimos años. Sin embargo, existe escasa información respecto a la interferencia que estos dispositivos podrían ocasionar en la fisiología deglutoria. En este contexto, y con el objetivo de describir el impacto de la CNAF y la VNI en la fisiología deglutoria, se realizó una revisión de la literatura en PubMed, Medline, Embase, Web of Science, Lilacs y Scielo. Se incorporaron estudios que incluyeran población ≥18 años, con uso de CNAF o VNI. Se excluyeron estudios en población con antecedentes de disfagia, necesidad de intubación, presencia de enfermedad neurológica, neuromuscular o respiratoria, entre otros. Los resultados de los estudios muestran que la CNAF podría disminuir el número de degluciones (en flujos ≥ 20 L/min; $p<0,05$), disminuir el tiempo medio de activación de la respuesta deglutoria proporcional al flujo empleado ($p<0,05$), incrementar el riesgo aspirativo en flujos altos (>40 L/min, $p<0,05$) e incrementar en promedio la duración del cierre del vestíbulo laríngeo ($p<0,001$). La VNI modo BiPAP, por su parte, podría aumentar el riesgo aspirativo debido al incremento en la tasa de inspiración post deglución (SW-I, $p<0,01$). Si bien la evidencia disponible es limitada, los resultados aportan información relevante a considerar en el abordaje de usuarios que utilicen estos dispositivos ventilatorios. Futuras investigaciones deberían ser desarrolladas para fortalecer la evidencia presentada.

Palabras clave:
Deglución; Trastornos de Deglución; Ventilación no Invasiva; Cánula Nasal de Alto Flujo

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INTRODUCTION

Swallowing, breathing, and eating functions are strongly related and require adequate coordination between them (Lefton-Greif & McGrath-Morrow, 2007; Matsuo & Palmer, 2008). This has been corroborated by neurophysiological studies, which have revealed the neuronal link between breathing and swallowing, identifying specialized neuronal networks at the level of the brainstem and cortex that coordinate these functions (Jean, 2001). According to the literature, four patterns can be observed in the breathing-swallowing relationship, the most frequent being expiration-swallowing-expiration (Boden et al., 2009; Hopkins-Rossabi et al., 2019; Martin-Harris, 2008).

In healthy adults, the swallowing process begins with exhalation, at low pulmonary volumes (Martin-Harris et al., 2003). At this moment, there is a pause in breathing –widely known as "swallowing apnea"– which is associated with a transient medialization of the vocal folds (VF) as protection, followed by their full adduction during the anteroposterior hyolaryngeal excursion. This excursion results in the opening of the pharyngo-esophageal segment (Martin-Harris et al., 2003). Swallowing apnea lasts approximately 1.0 to 1.5 seconds when swallowing liquids, and the time may vary depending on the viscosity of the bolus (Hopkins-Rossabi et al., 2019). Breathing then restarts as the larynx descends during the later phases of swallowing, and at this point is characterized by a reduced exhalation (Hopkins-Rossabi et al., 2019; Martin-Harris et al., 2003). During this process, exhalation causes the alveoli to collapse, reaching their resting position and producing a subglottic pressure higher than the atmospheric pressure (Gross et al., 2003). It is this high subglottic pressure, added to the airway closure due to the approach of the VF, that creates the ability to protect the airway and eliminate waste from it during swallowing (Martin-Harris, 2008).

The literature shows that swallowing can be negatively affected in patients with respiratory problems, due to the close relationship and dependence between both processes (Aoyagi et al., 2021; Ghannouchi et al., 2016; Langmore et al., 2021; Lin & Shune, 2020).

In recent years, the use of non-invasive ventilation devices has become common in hospital units, with their use being extended even beyond people with respiratory pathologies. These devices, unlike invasive ventilatory ones, allow patients to communicate verbally and feed orally. Depending on the clinical condition and its complexity, we can find different devices. One that has been widely used in recent years is the high-flow nasal cannula (HFNC), a large-diameter device that takes up approximately 50% of the internal nasal passages and can deliver high airflow volumes that reach up to 60-70 liters per minute (L/min). This air is humidified and tempered to the point of body temperature (close to 37°C), in addition to providing a fraction of inspired oxygen of up to 100% relative humidity (Nishimura, 2016). During normal breathing, inspiratory flow rates are approximately between 20 to 30 L/min; however, people with acute respiratory distress may require an inspiratory flow that exceeds 60 L/min (Katz & Marks, 1985; Rochwerg et al., 2019).

Another device that is widely used in clinical practice is non-invasive ventilation (NIV), which facilitates breathing by delivering pressure to the airway (Mehta & Hill, 2001). NIV provides positive pressure to the airway, which can be continuous (CPAP), creating a continuous flow and airway opening, or in two levels (BiPAP). BiPAP has two modes, Spontaneous or Spontaneous/Timed (S/T). In Spontaneous mode, the ventilator increases the patient's spontaneous breaths, while S/T mode offers a support rate slightly lower than the patient's respiratory rate (Schönhofer & Sortor-Leger, 2002). It is for this reason that, under certain conditions, NIV is considered an appropriate course to delay intubation, with its side effects and associated inconveniences for patients with acute respiratory failure (ARF) (Nava et al., 2009).

Although the use of NIV allows patients to communicate and swallow, it is not free of complications, which range from minor ones such as the discomfort associated with the use of the interface, aerophagia, or oral/nasal dryness, to major complications such as aspiration and hemodynamic effects (Gay, 2009).

Considering the physiology of swallowing and the mechanism of these devices, as well as the increase in their clinical use, a question arises regarding the impact that HFNC and NIV may have on swallowing. According to what has previously been stated, it can be hypothesized that these devices may compromise breathing-swallowing coordination and, therefore, airway protection, interfering with the swallowing process and increasing the risk of aspiration. Based on the above, the following review hopes to answer the question: What is the impact of high-flow nasal cannula (HFNC) and non-invasive ventilation (NIV) on the swallowing physiology of adult subjects? It is hoped that this review can provide tools to speech-language therapists –who work in the field of adult swallowing– that allow them to make decisions in the context of people using these non-invasive devices.

METHODOLOGY

A literature review was carried out in April 2022, which was updated in July 2022 and January 2023. The following databases were included: PubMed, Medline, Embase, Web of Science (WoS), Lilacs, and Scielo.

Search Strategy

The thesauri MeSH and Emtree as well as free search terms were combined for the search strategy. The terms "adult"[Mesh] and "adult*" were used for the population, combining them through the Boolean "OR". For the intervention, the terms "high flow nasal cannula", "high flow nasal cannula therapy", "high flow nasal cannula oxygen therapy", "oxygen nasal cannula", "*canula nasal de alto flujo*", "noninvasive ventilation"[Mesh], "continuous positive airway pressure"[Mesh], "continuous positive airway pressure", "non invasive ventilation", "non-invasive ventilation", "*ventilacion mecanica no invasiva", "ventilacion no invasiva*", "CPAP device", and "CPAP" were used, combining them through the Boolean "OR". Regarding outcome measures, the terms "swallow*", "normal swallow*", "deglutition"[Mesh], "deglutition", "deglutition physiology", "swallow* physiology", "swallow* function", "*deglución", "fisiologia deglutoria",* and *"deglucion normal"* were used, also combined through the Boolean "OR". The searches were combined with the Boolean "AND".

Table 1 schematizes the search terms used in this review.

Table 1. Search terms used for the review.

	Population	Intervention	Outcome
Pubmed	'adult' [Mesh] 'adult*'	'High Flow Nasal Cannula' 'Noninvasive Ventilation' [Mesh] 'Continuous Positive Airway Pressure' [Mesh] 'Non invasive ventilation'	'swallow*' 'normal swallow*' 'deglutition' [Mesh] 'swallow* physiology'
MEDLINE	'adult*'	'High Flow Nasal Cannula' 'Non-invasive ventilation' 'Noninvasive Ventilation' 'Continuous Positive Airway Pressure' 'CPAP'	'swallow*' 'deglutition' 'normal swallow*' 'swallow* physiology' 'swallow* function'
Embase	'adult*'	'high flow nasal cannula therapy' 'high flow nasal cannula oxygen therapy' 'noninvasive ventilation' 'continuous positive airway pressure' 'cpap device' 'oxygen nasal cannula'	'swallow*' 'deglutition physiology' 'normal swallow*' 'swallow* function'
WoS	'adult*'	'high flow nasal cannula therapy' 'high flow nasal cannula oxygen therapy' 'noninvasive ventilation' 'non-invasive ventilation' 'continuous positive airway pressure' 'oxygen nasal cannula' 'CPAP device'	'swallow*' 'deglutition' 'deglutition physiology' 'normal swallow*' 'swallow* function'
Lilacs	'adult*'	*'canula nasal de alto flujo'* *'ventilacion mecanica no invasiva'* *'CPAP'*	*'deglucion'* *'fisiologia deglutoria'* *'deglucion normal'*
Scielo	'adult*'	*'canula nasal de alto flujo'* *'ventilacion mecanica no invasiva'* 'CPAP'	*'deglucion'* *'fisiologia deglutoria'* *'deglucion normal'*

Search Criteria

The search criteria considered:

- Primary studies (randomized clinical trials, quasi-experimental studies, prospective and retrospective cohort studies, cross-sectional studies, case series, case reports, among others).
- Date of publication (studies published in the last 10 years).
- Language (English, Portuguese, and Spanish).
- Full-text availability.

Inclusion and Exclusion Criteria

The articles that met the search criteria were analyzed by title and abstract, according to the inclusion and exclusion criteria detailed below.

The following inclusion criteria were considered: population over 18 years of age, using HFNC or NIV.

The exclusion criteria were: studies where subjects had a history of dysphagia, required orotracheal intubation (OTI), and presented neurological, neuromuscular, or respiratory disease (OSAS, COPD, or other), as well as studies whose objectives were not consistent with the purpose of this research.

Procedures

First, the protocol for the study was created, defining the objectives of the review. Subsequently, the search strategy was developed, including the MeSH, Emtree, and DeCS and the free search terms. In parallel, a matrix was designed on Excel® for the preselection of articles and another one for primary data extraction.

The search was carried out through the previously mentioned databases. The articles meeting the search criteria were analyzed by title and abstract according to the inclusion and exclusion criteria established for this review.

Three authors performed an extensive blind review of the selected articles, synthesizing and adding the information to the predesigned matrix. This information included the type of design, objectives, intervention, results, and conclusions.

Variables of Interest

Despite the discrepancy between the outcomes found in the articles included in this review, a decision was made to unify the information based on 3 variables, to facilitate the interpretation and synthesis of the results. The 3 variables were: Population, type of invasive device, and swallowing outcome (the latter was described based on what each article reported).

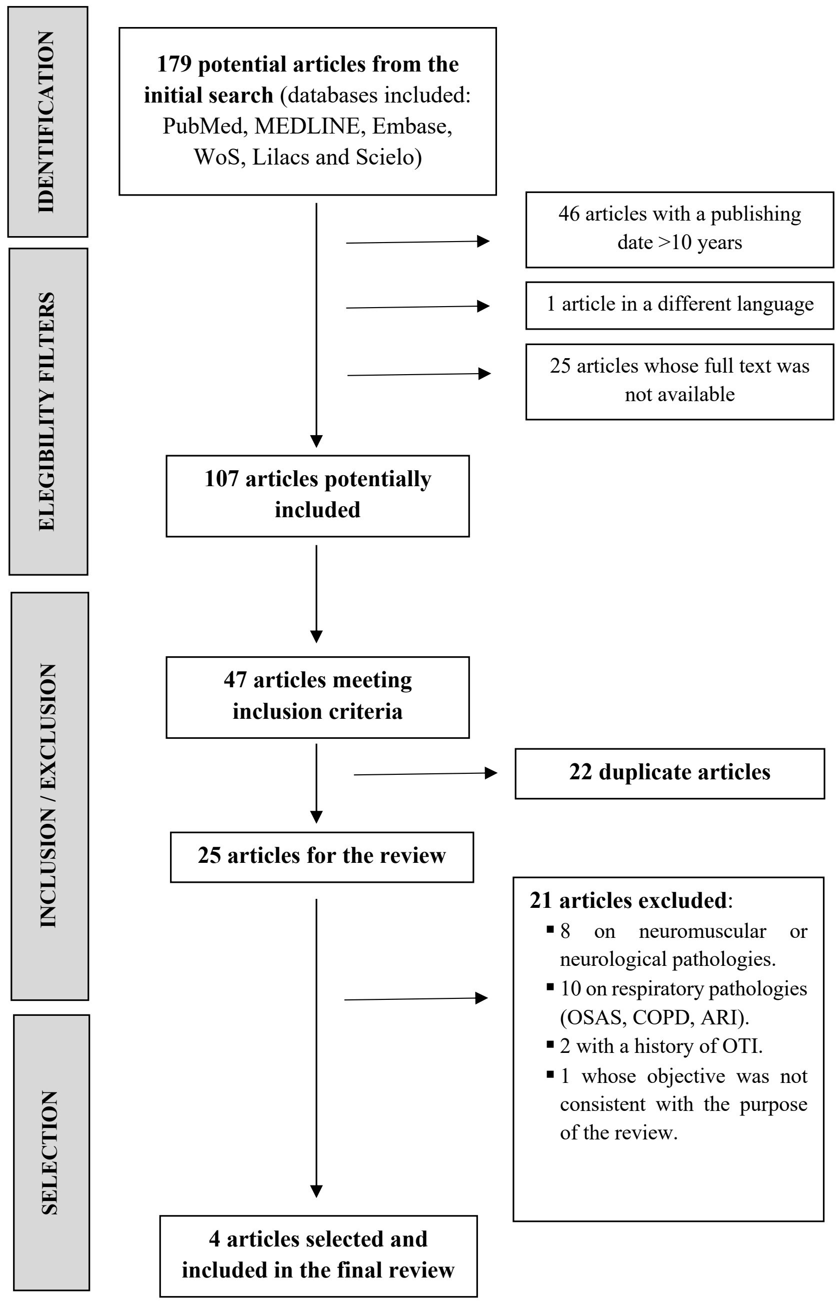
RESULTS

The initial search yielded a total of 179 potential articles, which were reduced to 107 after applying the search criteria. Only 47 articles met the inclusion criteria. Subsequently, 22 duplicate articles were eliminated, leaving 25 articles for analysis. Upon applying the exclusion criteria, 21 articles were excluded (8 for using a population with neuromuscular or neurological pathology, 10 for working with a population with respiratory pathology, 2 for including a population with a history of intubation, and 1 for presenting an objective that was not consistent with the purpose of this review). After this process, only 4 articles qualified for the review (see Figure 1). Of these 4 articles, 3 were quasi-experimental studies (Allen & Galek, 2021; Hori et al., 2016; Sanuki et al., 2017) and 1 a prospective cohort study (Arizono et al., 2021).

Annex 1 contains a table that summarizes each article included in the review in greater detail.

The results are described below, based on the previously mentioned variables of interest.

Figure 1. Flowchart describing the identification and selection of articles for the review.



Population

The total number of patients included in the review was 90, across the 4 articles that were analyzed (Allen & Galek, 2021; Arizono et al., 2021; Hori et al., 2016; Sanuki et al., 2017). The subjects were healthy adults, 35 men (38.9%) and 55 women (61.1%). The minimum number of participants per study was 9 and the maximum was 30. Only one study (Allen & Galek, 2021; n=29) did not include the average age of the subjects, the mean of the average age for the remaining subjects (n=61) was 40.97 ± 13.36 years.

Although the inclusion criteria for participants were not consistent across studies, they were mainly healthy adults over 18 years of age, without any relevant medical history. Additionally, two studies (Arizono et al., 2021; Hori et al., 2016), established as a selection criterion that subjects be able to perform 3 or more swallows in 30 seconds, based on the Repetitive Saliva Swallowing Test (RSST). As for the exclusion criteria, special emphasis was given to the presence of respiratory and neurological pathologies, as well as a previous history of dysphagia or pneumonia. For its part, the study by Allen & Galek (2021) excluded pregnant women (due to the risk of radiation exposure).

Use of Non-Invasive Ventilatory Device and its Outcomes Regarding Deglutition

High-Flow Nasal Cannula (HFNC)

Three of the four articles that were analyzed (Allen & Galek, 2021; Arizono et al., 2021; Sanuki et al., 2017) studied the high-flow nasal cannula (HFNC). They randomly analyzed the flow variations of the HFNC, finding a range of 0 to 60 L/min in the study by Arizono et al. (2021), with 0 L/min as the control condition. For their part, Allen & Galek (2021) used airflow measurements ranging from 10 to 60 L/min, while Sanuki et al. (2017) carried out their analysis with flows of 15 L/min, 30 L/min, and 45 L/min. A temperature of 37°C and a FiO2 of 21% were used in all three studies.

Regarding how swallowing outcomes were assessed, there was variability between the 3 studies. Arizono et al. (2021) used clinical tests such as the 30 mL water test (WST), repetitive saliva swallowing test (RSST), and self-perception of effort during the WST, which was quantified using a VAS scale (0 to 100, proportional to the perception of inability to swallow). For their part, Allen & Galek (2021), used videofluoroscopy (VFSS) to objectively measure performance when ingesting 20 mL liquid boluses, using the penetration-aspiration scale (PAS) to evaluate swallowing safety. Sanuki et al. (2017) assessed the intake of distilled water boluses, using a catheter that continuously administered 2 mL to determine breathing-swallowing coordination, and 5 mL to evaluate the activation of the oropharyngeal swallow response (OPSR). These volumes were used for each airflow. In parallel, the authors used electromyography (EMG) to measure swallowing parameters.

According to the outcomes analyzed, the results varied among studies. Table 2 summarizes the information on each study's parameters, outcomes, and results.

The outcome for the number of swallows was only reported in 2 of the 3 studies (Arizono et al., 2021; Sanuki et al., 2017). Arizono et al. (2021) reported that airflow variations with values equal to or greater than 20 L/min were associated with a significantly lower number of swallows in the RSST compared to flows of 0 L/min and 10 L/min ($p<0.05$). This indicates that an increase in airflow above 20 L/min would generate a decrease in the number of swallows. In contrast, Sanuki et. al. (2017) did not report statistically significant differences ($p=0.667$) in the number of swallows between groups (15 L/min, 30 L/min, and 45 L/min).

Concerning the physiology of swallowing, only the study by Sanuki et al. (2017) analyzed the mean activation time of the OPSR and the predominant phase in which swallowing occurred. As for the first variable, the authors reported that the mean activation times of the OPSR with different airflows were significantly shorter than those under control conditions (15 L/min: 9.8±2.9 sec.; 30 L/min: 9.0±2.7 sec.; 45 L/min: 8.5±3.0 sec.; control: 11.9±3.7 sec.) ($p<0.05$). For its part, the swallowing timing was predominantly in the expiratory phase for all groups, without statistically significant differences between groups ($p=0.409$).

Only two of the three articles assessed swallowing safety (Allen & Galek, 2021; Arizono et al., 2021). Arizono et al. (2021) reported choking episodes in 36.6% of the population (n=11 subjects) when ingesting 30mL of water with 10 L/min (1 subject), 40 L/min (5 subjects), and 50 L/min flows (5 subjects) (all with $p<0.05$). Flows higher than 40 L/min were associated the most with choking and a greater risk of aspiration in healthy individuals. For their part, Allen & Galek (2021) reported a total of 812 swallows among the 7 flow rates they analyzed, all of them with total closure of the laryngeal vestibule.

Regarding the duration of the laryngeal vestibule closure (dLVC), these results showed that high flows (50 L/min and 60 L/min) create greater variability in dLVC. However, the regression analysis revealed that the airflow rate delivered by HFNC significantly influenced dLVC ($p<0.001$), showing a positive relationship where the dLVC increased by 0.002 seconds on average for each unit increase in the airflow administered via HFNC. On the other hand, the same authors reported that PAS scores 1, 2, and 4 (considered normal) were found in 99.2% of the swallows analyzed, while PAS values 3, 7, and 8 (considered abnormal) were reported in a 0.2% (PAS 3) and 0% (PAS 7 and 8) of the swallows. No statistically significant association was found between the PAS scale score and the airflow administered through HFNC ($p=0.610$).

Finally, the study by Arizono et al. (2021) analyzed the self-perception of swallowing effort (rated with VAS) in isolation.

According to their results, the self-perception of swallowing effort increased significantly ($p<0.05$) for all flow comparisons [flows equal to or greater than 20 L/min when compared with 0 L/min; 30 L/min when compared to 10 L/min; 40 L/min when compared with 10 L/min and 20 L/min; 50 L/min when compared with all other flows], all of them with p values <0.05.

Table 2. Impact of HFNC on swallowing physiology.

Author(s)	Parameters used in HFNC	Assessment of swallowing outcomes	Main results
Arizono et. al., 2021 (n=30)	• Flow: 0 to 60 L/min • T° 37°C • Fio2 21%	• Water swallow test with 30 mL. • Repetitive Saliva Swallowing Test (RSST). • Self-perception of effort in WST (0 to 100 VAS).	• Decrease in the number of swallows as the airflow increases above 20L/min (p<0.05). • Flows greater than 40 L/min were associated with a greater risk of aspiration (p<0.05). • Increase in the self-perception of swallowing effort as the flow increases (p<0.05).
Allen & Galek, 2021 (n=29)	• Flow: 10 to 60 L/min • T° 37°C • Fio2 21%	• Videofluoroscopy (20mL of liquid). • Penetration-Aspiration Scale (PAS).	• The amount of airflow administered by HFNC significantly influenced the duration of laryngeal vestibule closure (dLVC) (p<0.001). • A positive relationship was found between units of administered flow and dLVC. For each unit increase in the airflow administered via HFNC, dLVC increased on average by 0.002 seconds. • There was no statistically significant association between the PAS scale score and the administered airflow (p=0.610).
Sanuki et. al., 2017 (n=9)	• Flow: 15-30-45 L/min • T° 37°C • Fio2 21%	• Continuous liquid boluses of 2 and 5 mL. • Electromyography (EMG).	• No statistical differences in the number of swallows (p=0.667). • Mean OPSR activation time was shorter in the different flows when compared to control (p<0.05). • Timing of swallowing was predominantly in the expiratory phase, without differences between groups (p=0.409).

Non-Invasive Ventilation (NIV)

Only one of the four articles (Hori et al., 2016) used non-invasive ventilation for their research. In this study, 22 subjects were distributed in 2 groups (G1: 12 individuals, average age of 28±11.5 years; G2: 10 individuals, average age of 73.9±5.8 years), and their breathing-swallowing coordination was analyzed by simultaneously monitoring respiratory flow, laryngeal movement, and swallowing sounds, in three different ventilatory conditions: control, continuous positive airway pressure (CPAP), and biphasic positive airway pressure (BiPAP). For CPAP, a pressure of 4 cmH2O was used, while BiPAP applied an inspiratory positive airway pressure (IPAP) of 8 cmH2O and an expiratory positive airway pressure (EPAP) of 4 cmH2O, with a rate of 10 breaths per minute. The occurrence of swallowing-associated non-inspiratory flow (SNIF) was also evaluated during non-invasive ventilation (CPAP and BiPAP). This is defined for research purposes as a slight inspiratory flow that occurs after swallowing apnea. Additionally, the phase of the respiratory cycle where a swallow occurs during CPAP and BiPAP was compared. Swallowing was evaluated using the repetitive saliva swallowing test (RSST), which consists of 3 swallowing series (with a swallow every 10 seconds), in 5 trials, with 15 swallows in total. Table 3 summarizes the main results of this study.

It was observed that swallowing-associated non-inspiratory flow (SNIF) was present in 68.3%±36.6%, 91.6%±8.1%, and 86.7%±10.2% during control breathing, CPAP, and BiPAP, respectively. However, there was no statistical difference between the SNIF occurrence rates for any condition (p=0.134). Furthermore, there was no statistical difference between the phases of the respiratory cycle where a swallow begins during

CPAP and BiPAP. The phases of the respiratory cycle where swallowing occurs were normally distributed, therefore swallows occurred most frequently in the middle of the expiratory phase.

Table 3. Impact of NIV on swallowing physiology.

Authors	Parameters	Assessment of Swallowing Outcomes	Main Results
Hori et. al., 2016 (n=22)	• Control: No pressure applied • BiPAP: IPAP 8cmH20 / EPAP 4 cmH20 • CPAP: 4cmH20 pressure	• Repetitive Saliva Swallowing Test (RSST).	• The rate of occurrence of swallowing-associated non-inspiratory flow (SNIF) showed no statistical difference for any condition ($p=0.134$). • No statistical difference was found between the phases of the respiratory cycle where swallowing initiates during CPAP and BiPAP ($p>0.05$). • Swallows were normally distributed, occurring most frequently in the mid-expiratory phase. • The occurrence rate of post-swallow inspirations (SW-I) was higher in BiPAP than in the control condition and CPAP ($p<0.01$). • The occurrence rate for SW-I in BiPAP was statistically correlated with swallow count in the RSST ($p<0.05$), SNIF occurrence rate, and age (both with $p<0.01$). • The occurrence rate for SNIF and swallow count in RSST would be predictor variables that affect SW-I during BiPAP (both $p<0.01$). • The occurrence rate of post-swallowing expiration (SW-E) in BiPAP was statistically correlated with SNIF occurrence rate ($p<0.05$) and age ($p<0.01$).

Upon evaluating the occurrence rate of post-swallow inspiration (SW-I), RSST count, SNIF rate, and age, it was found that, in both groups, the occurrence rate of post-swallowing inspiration (SW-I) was higher with BiPAP compared to the control and CPAP conditions ($p<0.01$). Furthermore, the SW-I occurrence rate in the BiPAP condition was significantly correlated with the RSST count ($\rho=0.490$; $p<0.05$), the SNIF occurrence rate ($\rho=0.626$; $p<0.01$) and age ($\rho= -0.557$; $p<0.01$). A negative correlation was observed between age and RSST count ($\rho= -0.631$; $p<0.001$). On the other hand, the occurrence rate of post-swallowing expiration (SW-E) with BiPAP was significantly correlated with the SNIF occurrence rate ($\rho= -0.624$; $p<0.05$) and age ($\rho=0.558$; $p<0.01$).

On the other hand, the multiple regression analysis used to determine the factors affecting post-swallow inspiration during BiPAP showed that the occurrence rate of SNIF ($R^2=0.664$; $p=0.000$) and the RSST count ($R^2=0.664$; $p=0.002$), would be predictor variables (both with $p<0.01$).

These results on breathing-swallowing coordination during NIV in healthy subjects suggest that the occurrence rate of SNIF may trigger inspiratory support in BiPAP mode, increasing the risk of aspiration. Therefore, swallowing should be carefully observed during non-invasive ventilation in BiPAP mode.

DISCUSSION

This review aimed to describe the impact of high-flow nasal cannula (HFNC) and non-invasive ventilation (NIV) on the swallowing physiology of adult subjects. Firstly, the results of the review show that research studying this relationship is scarce. Secondly, different results can be found regarding the impact of these devices on the physiology of swallowing, depending on the outcomes and methodology of each study. For these reasons, and considering the small sample size and the methodological limitations of each study, the results of this review must be analyzed with caution and are not widely generalizable.

Regarding HFNC, Arizono et al. (2021) reported a statistically significant decrease in the frequency or number of RSST swallows with flows equal to or greater than 20 L/min. This is contrary to what was observed by Sanuki et al. (2017), who did not report statistically significant differences in the number of swallows for the groups they analyzed. It should be noted that, although some contradictions can be found between the results reported by these studies, this could be explained by how the outcomes are analyzed. The findings of Arizono et al. (2021), which point to changes in the number of swallows during RSST, are based on successive swallows of saliva boluses. However, these authors did not report differences in WST with different airflows. For their part, Sanuki et al. (2017) analyzed the number of swallows based on the water boluses administered for each flow. Therefore, both studies differ regarding the type of bolus used for the assessment, which could have conditioned the activation of the oropharyngeal motor response. It is important to mention that the analyses and differences are objectively evaluated based on the intrasubject variation throughout the measurements. In this sense, it seems relevant to highlight the airflow variations that are found. In the first study (Arizono et al., 2021), variable random flows were used in the range of 0 L/min to 60 L/min, which implied a greater number of measurements and, therefore, a greater possibility of fatigue observed in the number of swallows in the RSST (which would justify the decrease in the number of swallows). For its part, in the second study (Sanuki et al., 2017), flows of 15 L/min, 30 L/min, and 45 L/min were used, which could have resulted in lower range variability and, therefore, greater intrasubject adaptability. Moreover, in the study by Sanuki et al. (2017), the administered flows were not compared with a baseline flow (0 L/min), unlike what was done by Arizono et al. (2021). Another relevant finding by Sanuki et al. (2017) relates to the average activation time of the OPSR. Here, it was observed that the OPSR was significantly lower under all airflow conditions, compared to the baseline. This would be closely linked to the capacity for adaptation and response of the swallowing function and our system, in the face of external conditions that challenge it to react quicker.

Concerning swallowing safety with HFNC, certain differences are found. Arizono et al. (2021) report choking episodes during the WST in 36.6% of the population (n=11/30). Particularly, flows greater than 40 L/min are associated with a greater number of choking episodes, thus increasing the risk of aspiration. It should be noted that although these results are based on clinical observations, they lack objective elements to provide solidity to the results. In this context, Allen & Galek (2021) objectively showed (through VFSS) that there was no statistically significant association between penetration-aspiration (according to the score on PAS) and the airflow administered through HFNC. In addition, they demonstrated that the flow administered by HFNC significantly influences the laryngeal vestibule closure duration (dLVC) in healthy adults, revealing a positive relationship that generates on average an increase of 0.002 seconds. That is, for every additional 1 L/min, dLVC increases on average by 0.002 seconds. These results are not surprising when we think about the variability in laryngeal vestibule closure for airway protection that has been reported in healthy subjects. It is known that the laryngeal vestibule closure can vary according to the type of bolus, its volume, the age of the subject, and the swallowing method (for example, continuous swallows), among others (Vose & Humbert, 2019). In this sense, the dLVC modulation in response to the airflow level emphasizes the ability of healthy adults to adapt to swallowing conditions as necessary, to ensure adequate airway protection.

A noteworthy aspect found in the studies using HFNC (Allen & Galek, 2021; Arizono et al., 2021; Sanuki et al., 2017) is the fraction of inspired oxygen (FiO2). FiO2 is the concentration of oxygen that a person inhales and, therefore, participates in gas exchange at the alveolar level (Peacock, 1998), which can represent the clinical inspiratory demand. Under normal conditions, FiO2 is 21%, as was used in the aforementioned studies (considering the population of healthy adult subjects). However, in pathological conditions, this value can fluctuate from 21% to 100%. FiO2 values are essential for adequately treating patients with hypoxemia, because cell damage and death can occur when oxygen consumption and supply do not coincide (Allardet-Servent et al., 2019). As there is a greater need for FiO2, respiratory demand increases, which may influence breathing-swallowing coordination. In particular, critically ill patients who are connected to ventilatory devices require a FiO2 modification, which could also interfere with swallowing. This is why future research should consider these variations in FiO2 and contrast them with the results obtained from healthy subjects.

As for the influence of NIV on the swallowing function, the study by Hori et al. (2016), the only one to include this device, showed that swallowing responses occurred more frequently in the expiratory phase, regardless of the modality that was used (CPAP or BiPAP). Furthermore, they reported no variation in swallowing-associated non-inspiratory flow (SNIF) under any condition. This shows that the behavior of swallowing onset for normal subjects remains in the expiratory phase (Krishnan et al., 2020; Martin-Harris, 2008). However, it was observed that the occurrence rate of post-swallow inspiration (SW-I) was higher in the BiPAP modality than in the CPAP or control conditions. This led the authors to perform correlation analyses for the BiPAP modality. Thus, they showed that the occurrence rate of SW-I with BiPAP was significantly associated with RSST count, SNIF occurrence rate, and age. These results suggest that the SW-I rate is directly related to the RSST count and the SNIF rate, and indirectly to age. The most relevant aspect of these results is the positive association between SW-I (post-swallowing inspirations) and the occurrence rate of SNIF. This association shows that SW-I is caused by the supporting inspiratory pressure that triggers SNIF, suggesting that post-swallowing inspirations (SW-I) during BiPAP were partially triggered by SNIF. Therefore, the results on breathing-swallowing coordination during NIV in adult subjects imply that SNIF could trigger inspiratory support in the BiPAP mode, increasing inspiration after swallowing (SW-I), which could increase the risk of aspiration.

It is important to note that the differences found in the variables that were analyzed, as well as in the methods and consistencies used to evaluate swallowing, restrict the generalization of these results. No homogeneity was found regarding the procedures, tests, and scales used, which ranged from clinical tests such as RSST and WST to objective assessments such as VFSS and EMG. Although the three studies on HFNC (Allen & Galek, 2021; Arizono et al., 2021; Sanuki et al., 2017) used liquid boluses, justified by the greater difficulty and precision required to manage this viscosity during the swallowing process, there is variability in the volumes and the procedures used to administer the liquid. The study by Hori et al. (2016) was the only one that included NIV. However, their analysis of the swallowing process was carried out using only RSST, without objective measures.

In relation to the above, it seems relevant to us to discuss the variability of the boluses, as well as the differences in consistency and volume. A systematic review by Krishnan et al. (2020) sought to describe and analyze respiratory function before, during, and after swallowing in healthy subjects, using different types of boluses. The results of this review show a lack of consensus on the effect of the characteristics of the bolus on the duration of swallowing apnea. In some cases, the volume of the bolus prolonged the duration of swallowing apnea, while in others it did not. Similarly, thicker consistencies (honey and thicker liquids) prolonged the duration of apnea. A common finding was the increased incidence of expiratory phase after spontaneous swallows when using a small bolus volume and uniform consistency. However, increasing the bolus volume and introducing mixed-consistency boluses increased the incidence of non-expiratory swallows (inspiration-swallow-inspiration or expiration-swallow-inspiration). These bolus modifications (changes in volume greater than 10 mL and consistency thick as honey) altered the typical swallowing pattern, increasing the frequency of inspiration after swallowing (consequently increasing the risk of aspiration). Thus, it should be considered that a higher bolus volume may not prolong swallowing apnea, but it may alter the respiratory phase in which swallowing occurs, changing to inspiratory rather than expiratory cycles.

In general, the results of this review suggest that both the use of HFNC and NIV could interfere with the physiology of swallowing. This is a relevant finding because both ventilatory devices are widely used in hospital clinical practice, especially in Critical Care Units (CCU), where a significant proportion of patients require ventilatory support through non-invasive devices, either as a first line of treatment or once they are weaned from invasive ventilation. Therefore, it is possible that these people, in addition to being at high risk of developing dysphagia, experience an increased risk of aspiration when using these devices. However, this information should be analyzed with caution, considering the clinical pathologies to which the subjects are exposed, as well as the clinical characteristics of critically ill patients, whose swallowing performance is often interfered with by other conditions such as sedation, delirium, weakness acquired in the ICU (ICU-AW), and pharmacological aspects, among others (Zuercher et al., 2019).

It should be mentioned that the objective of this review was to determine the impact of HFNC and NIV on the swallowing physiology of healthy adult subjects, representing a starting point for understanding the influence of these mechanisms on swallowing and associating their use with swallowing physiology and pathophysiology. Most of the studies in this review, except for Hori et al. (2016), included only adult subjects –in their majority young– who were healthy, thus excluding older people. It is known that older adults, in addition to their medical history, have a particular swallowing pattern, which should be profiled and included in future research. This would aim at understanding the positive or negative repercussions of non-invasive ventilatory devices in this population. On the other hand, subjects with chronic respiratory diseases (mainly COPD) frequently require the use of these ventilatory devices and experience swallowing difficulties (Ghannouchi et al., 2016; Terada et al., 2010), which could increase their risk of aspiration. Particularly in people with neuromuscular diseases, the use of non-invasive ventilation devices is often permanent due to their underlying pathophysiological condition, with the feeding process being documented by several studies (Britton et al., 2020; Garguilo et al., 2016; Kinnear et al., 2021). One of these articles even proposes that NIV would improve breathing-swallowing coordination in people with neuromuscular pathologies and patients who are chronically dependent on ventilatory support (Garguilo et al., 2016). The information exposed above, added to the clinical relevance of these devices, shows the need to carry out future research on older adults, people with dysphagia, people with acute or chronic respiratory diseases, and any other specific groups who widely use these devices (such as patients with neuromuscular pathologies).

Besides the explicit limitations of the studies that were analyzed, this review is not free of limitations. The main one is found in the exclusion criteria (subjects with a history of dysphagia, orotracheal intubation, neurological, neuromuscular, or respiratory diseases, as well as objectives not consistent with the purpose of the research), which restricted the number of articles that could be analyzed, as well as the target population. However, this can be explained by the objective of the review, which sought to determine the influence of these ventilation devices on swallowing physiology and did not intend to analyze swallowing pathophysiology, as could be the case with other populations with swallowing disorders who also use non-invasive ventilation devices (for example, people with respiratory diseases). Nonetheless, and although this is a scarcely studied topic with few publications and a limited level of evidence, the present review can set the basis for inquiries that allow speech-language therapists working in the field of swallowing to consider other elements that could affect the performance of patients using non-invasive devices such as HFNC and NIV. It is important to mention that, as of the date when this manuscript was written, a similar review was found (Devlin & O'Bryan, 2021) which focuses only on subjects with HFNC. The methodology used in said review differs from the one in this manuscript since the studies, with their results and limitations, were only analyzed individually, without extrapolating or analyzing the information globally as has been done in this review. Moreover, the aforementioned review does not specify the inclusion or exclusion criteria of the studies. Despite this, there are similarities between their results and ours, since many of the studies included in that review correspond to those analyzed here.

In summary, the results of this review show that non-invasive ventilation has an impact on the physiology of swallowing. However, the results of the different studies varied depending on the outcome that was analyzed and the methodology used. Furthermore, the population was limited to healthy people. Therefore, it is essential to develop future research that considers these methodological aspects, as well as new reviews that include different populations such as older people, people with respiratory conditions, or critically ill patients, among others, as well as studies that use objective assessment methods.

CONCLUSIONS

The evidence on the impact of HFNC and NIV on the physiology of swallowing is limited. In light of what has been found through this review, we can assert that both devices could interfere with swallowing physiology. However, these results should be used with caution, considering the respective methodological limitations. In particular, NIV/BiPAP could increase the risk of aspiration due to an increase in post-swallowing inspiration (SW-I), while HFNC could reduce the number of swallows (at flows $\geq$ 20 L/min), reduce the average time of OPSR activation proportional to the airflow, increase aspiration risk at high flows (>40 L/min), and increase the dLVC by 0.002 seconds on average for every 1 L/min of increase in flow. Future research that considers the methodological limitations of each study and includes other types of populations should be carried out to strengthen this evidence. Moreover, clinical speech-language therapists should take this information into account when working with patients who use these ventilation devices.

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Appendix 1. Synthesis of the articles included in this review.

#	Author(s) and Year	Objective	Population	Intervention(s)	Main Results	Design
1	Arizono, S. et. al., 2021	To examine the effect of HFNC flow rate on swallowing function in healthy individuals, in order to prove that increasing HFNC flow negatively affects swallowing function and effort in healthy volunteers.	30 adult volunteers >18 years old, healthy, with no history of pneumonia, lung conditions, and/or cerebrovascular disease, able to swallow ≥ 3 times in 30 sec. Mean age (S.D.): 29.9±6.7 years. 19 (63%) women vs. 11 (37%) men.	The subjects underwent two days of testing. During the first day, they were subjected to anthropometry, lung function tests, peak cough flow, respiratory muscle strength test (maximum inspiratory and expiratory pressure), phonatory function test (pharyngeal dysfunction, maximum phonation time), and tongue pressure measurement. During the second, subjects were exposed to HFNC (0, 10, 20, 30, 40, and 50 L/min) and FiO2 0.21, in random order. Each test lasted 5 minutes and the subjects were given a 5-minute rest between each one. Subjects were tested using the 30 ml water swallow test (WST) and repetitive saliva swallowing test (RSST) under each flow condition. Additionally, they were asked to rate their self-perceived swallowing effort during the WST, using a visual analog scale (VAS) from 0 to 100, where 0 was normal and 100 was total inability.	Of the total number of subjects, 11 (36.6%) had choking episodes during the 30 ml water swallowing test at 10 L/min (1), 40 L/min (5), and 50 L/min (5) (all with $p<0.05$). Swallowing effort, rated using VAS, increased significantly for flows equal to or greater than 20 L/min compared to 0 L/min ($p<0.05$). Furthermore, swallowing effort at 30 L/min was significantly greater than at 10 L/min ($p<0.05$), significantly higher at 40 L/min than at 10 and 20 L/min ($p<0.05$), and significantly higher at 50 L/min compared to all other flows ($p<0.05$). Flow variations equal to or greater than 20 L/min resulted in fewer swallows in RSST compared to 0 and 10 L/min ($p<0.05$). It was concluded that flows greater than 40 L/min were associated with choking and a greater risk of aspiration in healthy individuals. Furthermore, during the RSST it was evident that swallowing frequency decreased with each flow increase.	Prospective Cohort
2	Allen K. & Galek K., 2021	To investigate the influence of the airflow provided by HFNC on the duration of laryngeal vestibule closure and describe the impact of HFNC airflow on the airway.	Initially, 40 adult subjects (under 60 years of age) were recruited. Any healthy adult was eligible for the study. Exclusion criteria included a history of respiratory disease,	Airflow measurements of 10, 20, 30, 40, 50, and 60 L/min and FiO2 of 0.21 were applied. Videofluoroscopy (VFSS) was used, where each participant ingested liquid boluses mixed with Barium, under multiple airflow conditions. The liquid consistency was selected considering that the swallowing	A total of 812 swallows were detected across the seven airflow variations. All swallows were performed with complete laryngeal vestibule closure (dLVC). Intra-rater reliability was excellent for the dLVC for 4 raters, which meant that one rater was excluded from the analysis. Inter-rater reliability was excellent (ICC=0.975 with a 95% confidence interval=0.968–0.980).	Quasi-Experimental

neurological deficit, dysphagia or difficulty swallowing, and pregnancy. The final analysis was performed on 29 subjects (26 women (89.7%) and 3 men (10.3%)), excluding 11 subjects due to recording errors. The age range is not specified.

process requires greater precision in a healthy population and, therefore, more sensitivity to results is needed. Initially, 1 ml was used without airflow, to allow participants to adapt to the Barium intake, then 20 ml was administered using HFNC with 0 L/min (control condition), 10 L/min, 20 L/min, 30 L/min, 40 L/min, 50 L/min, and 60 L/min. The flow conditions were programmed through a random generator to avoid following an order and for participants to know the specifications. Additionally, a video presentation with slides and audio narration of the instructions was also used. During each airflow variation, the subjects were given the instruction "Pour the entire contents of the cup into your mouth and hold it until I tell you to swallow." A research assistant made sure that the participants poured all of the Barium into their mouths and that the glass was empty. The participants were then told to "swallow the contents of the glass in one go." The penetration-aspiration scale (PAS) was used to categorize the swallows, which were analyzed by 5 evaluators. Then, 20% of the videos were randomly selected and repeated by each rater 1 week after initial completion.

The reliability of the duration of laryngeal vestibule closure (dLVC) was obtained from a mean score (k=5) calculated from the intraclass coefficient (ICC). Linear regression estimates were used to determine the influence of HFNC airflow on dLVC. A prediction model indicated the amount and

For the PAS score, intra-rater agreement was 90% or greater for all raters.

Regarding the first objective, "to determine the influence of the airflow delivered through HFNC on dLVC", during the data analysis, linear regression revealed that the amount of airflow applied through HFNC significantly influenced the dLVC, $F(1,810)=19.056$, $p<0.001$. This relationship was positive, meaning that when the airflow increased, dLVC also increased. For each unit increase in airflow, dLVC increased on average by 0.002 seconds.

As for the second objective, "describe airway invasion during airflow through HFNC," the mode for each airflow condition was PAS 2, with >80% frequency compared to other scores. Across the entire data set, PAS scores 1,2, and 4 represented 99.2% of all swallows. These scores are considered normal during swallowing, while PAS 3, 7, and 8 are considered abnormal. PAS 3 occurred in 0.2% of swallows there was no aspiration (PAS 7 or 8) (0% of swallows). A Fisher's exact test was carried out to determine the association between PAS score and airflow. No statistically significant association was found ($p=0.610$). Therefore, the change in airflow provided through HFNC was not associated with a change in airway invasion in healthy adults.

It is concluded that, in healthy young adults, airflow applied through HFNC influences dLVC in a flow-dependent manner. The influence of HFNC on dLVC shows a positive relationship, meaning that dLVC increases when airflow increases and vice versa. At very high flow levels (50 and 60 L/min), healthy adults in this study had greater dLVC variability. Airway invasion was

				direction of change in dLVC for each unit of airflow.	essentially unchanged under all airflow conditions. Modulation of the dLVC in response to the amount of airflow highlights the ability of healthy adults to adapt to swallowing conditions as a requirement to protect the airway.	
3	Sanuki T. et. al., 2017	To assess the effects of HFNC on swallowing function (swallowing reflex).	9 healthy Japanese subjects (9 men, 0 women) with a mean age of 32.1 (s.d. ±5.9) years and a mean BMI of 22.2 (s.d. ±1.2). Subjects with no history of dysphagia or diseases that can cause dysphagia, such as stroke or Parkinson's disease.	Initially, each subject was evaluated at rest, under control conditions without HFNC intervention for 5 min. They were then exposed to HFNC at three different flow rates (15, 30, and 45 L/min) in random order. The flow was delivered by the HFNC system (AIRVO™, Fisher & Paykel Healthcare) through a nasal cannula. The HFNC system was configured to deliver a 0.21 FiO2 concentration at 37°C during the three different flow interventions. The swallowing reflex was induced by infusion and administration of a distilled water bolus, through a flexible polyethylene catheter and simultaneously measured with electromyography (EMG). After each application, there was a calibration time of 2 min, and there was a 1-minute interval between the infusion and the administration of the bolus. All tests of statistical significance were bilateral and p-values <0.05 were considered statistically significant.	The mean latency times found in the swallowing reflex with flows of 15 L/min (9.8±2.9 s), 30 L/min (9.0±2.7 s), and 45 L/min (8.5 ±3.0 s) were significantly shorter than those observed under control conditions (11.9±3.7 s; p<0.05). All nine subjects completed the experimental protocol. Respiratory frequency at 30 L/min (mean: 8 [95% CI: 6.8–15.2] p=0.048) was significantly lower than in control conditions (mean 15 [95% CI: 9–17.2]), except at 15 L/min (mean 13 [95% CI 8–15.2] p=0.720) and 45 L/min (mean 10 [95% CI 8.2-13.4] p=0.089). Swallowing frequency (p=0.667) and swallowing time in relation to the respiratory phase (p=0.409) were very similar in all conditions. It is concluded that HFNC can improve swallowing function with increasing flow levels, by reducing the latency of the swallowing reflex. This would allow oral intake to be maintained without risk of aspiration during airflow administration, under the studied conditions.	Quasi - Experimental
4	Hori R. et. al., 2016	To prove the hypothesis that the risk of silent aspiration increases in non-invasive positive pressure ventilation.	12 healthy young volunteers (8 men and 4 women), with a mean age of 28 years (s.d. ± 11.5 years), and 10 healthy older volunteers (4 men and 6 women), with a	Breathing-swallowing coordination was measured and analyzed by simultaneously monitoring respiratory flow, laryngeal movement, and swallowing sounds. Respiratory flow was monitored using a sensor placed in the cannula (Pro-Tech	When SNIF did not activate the inspiratory support, a small inward flow was observed in the flow signal, as well as a small oscillation from negative to positive pressure in the pressure signal. This oscillation was due to the expiratory positive airway pressure (EPAP) level control in response to SNIF. When comparing SNIF under	Quasi-Experimental

mean age of 73.9 years (S.D. ± 5.8 years).

All subjects were able to swallow more than three times per 30 seconds in the repetitive saliva swallowing test (RSST) and had no history of aspiration pneumonia, cerebrovascular diseases, or respiratory failure.

ProFlow) and a differential pressure transmitter. Laryngeal movement and swallowing sounds were recorded simultaneously using a custom-made piezoelectric pressure sensor that was placed on the skin surface around the thyroid cartilage. The analysis was performed using MATLAB software. Swallows were detected based on laryngeal movements and the absence of respiratory flow (swallowing apnea >400 ms). The sensitivity was 100% and the specificity was 86.6%.

A Respironics® non-invasive ventilator was used to fulfill the ventilatory conditions.

The breathing-swallowing coordination was analyzed by simultaneously monitoring respiratory flow, laryngeal movement, and swallowing sounds in three different ventilatory conditions: control, continuous positive airway pressure (CPAP), and biphasic positive airway pressure (BiPAP). The different ventilatory conditions were: control, CPAP (4 cmH2O), and BiPAP (IPAP 8 cmH2O and EPAP 4 cmH2O). The subjects were in a supine position, head tilted 30° upward, and wore a full-face interface. A repetitive saliva swallowing test (RSST) was carried out, consisting of 3 series of swallowing (with a swallow every 10 seconds), in 5 trials, performing 15 swallows in total. The swallowing-associated non-inspiratory flow (SNIF) occurrence rate during non-invasive ventilation was also measured using custom analysis software.

the control, CPAP, and BiPAP modes, it was observed in 68.3% ± 36.6%, 91.6% ± 8.1%, and 86.7% ± 10.2%. There was no statistical difference between the SNIF occurrence rates (Friedman test, p=0.134).

There was no statistically significant difference between the phases of the respiratory cycle where a swallow was initiated during CPAP and BiPAP (CPAP 0.71±0.28 and BiPAP 0.73±0.26). The phases of the respiratory cycle where swallowing was initiated were normally distributed. In other words, swallows occurred most frequently in the mid-expiratory phase. Upon evaluating SW-I, RSST count, SNIF rate, and age, it was observed that, in both groups, the SW-I occurrence rate was higher with BiPAP compared to the control and CPAP conditions. The SW-I occurrence rate in the BiPAP condition was significantly correlated with the RSST count (p=0.490), SNIF occurrence rate (p=0.626), and age (p=0.557). A negative correlation was observed between age and RSST count (p=0.631), which explains the decrease in the number of swallows as age increases. The occurrence rate of post-swallowing expiration with BiPAP was significantly correlated with the SNIF occurrence rate (p=0.624) and age (p=0.558).

In the multiple regression analysis, with SW-I occurrence rate as the dependent variable, RSST count and SNIF occurrence rate were extracted as predictor variables (R=0.815, adjusted R2=0.628, p<0.05).

It is concluded that the occurrence rate of post-swallowing inspiration increases with the use of BiPAP, regardless of age. The results suggest that swallowing-associated non-inspiratory flow may

The statistical analysis was performed using SPSS and the Friedman test to compare the SNIF occurrence rates during control, CPAP, and BiPAP breathing, as well as to compare the appearance frequencies of each respiratory phase after swallowing under these conditions, between young and older subjects. The Bonferroni adjustment test was used for multiple comparisons post hoc. Spearman's rank correlation coefficient was used to assess the correlation between post-swallow inspiration occurrence rate (SW-I) and RSST count, SNIF occurrence rate, and age.

A multiple regression analysis was performed with the SW-I occurrence rate as the dependent variable. The phases of the respiratory cycle to initiate a swallow during CPAP and BiPAP were compared using unpaired t-tests. A p-value <0.05 was considered for statistical significance.

trigger inspiratory support in the BiPAP mode, increasing the risk of aspiration.