Chapter

Expiratory Muscle Training in Motor Neuron Diseases: Impact on the Upper Airways

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Abstract

Amyotrophic lateral sclerosis (ALS) is a progressive and idiopathic neurodegenerative disease with no known cure, influenced by a variety of factors. The survival of individuals with ALS is closely tied to the effective management of symptoms, particularly the preservation of respiratory and motor functions. This chapter focuses on the importance of clinical protocols designed to delay respiratory deterioration, emphasizing the role of noninvasive ventilation (NIV) and upper airway expiratory techniques in extending survival and enhancing the quality of life. Multidisciplinary approaches in ALS care aim to postpone the need for tracheostomy, with a central focus on NIV to optimize lung function and improve patient outcomes. The use of ventilators with mouthpiece interfaces contributes not only to respiratory safety but also to the preservation of voice quality. Additionally, expiratory muscle training enhances the strength of muscles involved in breathing, leading to significant improvements in respiratory function.

Keywords: amyotrophic lateral sclerosis, muscle training, noninvasive ventilation, motor neuron diseases, respiratory exercises

1. Introduction

Motor neuron diseases (MNDs), including amyotrophic lateral sclerosis (ALS), manifest in various ways. Moreover, respiratory changes play a crucial role in disease progression and patient survival [1]. Respiratory infection, secondary to impaired respiratory defenses, chest wall restriction, weak cough, and recurrent respiratory tract infections, is the leading cause of morbidity and mortality in this population.

ALS can be subdivided into bulbar onset and limb onset based on the somatic region involved [2]. Respiratory complications are particularly prevalent and fatal in patients with bulbar-onset alS, accounting for more than 85% of deaths. In contrast, limb-onset alS is associated with longer survival, although respiratory dysfunction still occurs as the disease progresses [3].

Restrictive ventilatory impairment is a common feature in most MNDs. As the disease progresses and lung volumes decrease, individuals lose the ability to inhale and cough effectively, which can lead to hypercapnia, respiratory failure, and the need for home mechanical ventilation. Eventually, most individuals die due to these

complications. The reduction in vital capacity (VC) is an indicator of respiratory muscle weakness, both inspiratory and expiratory, but the loss of lung volume tends to be greater than expected based solely on muscle weakness [4].

Multidisciplinary interventions for ALS patients aim to delay the need for tracheostomy, focusing on noninvasive ventilation (NIV), which improves survival and preserves lung capacity. Using ventilators with a mouthpiece attachment contributes to respiratory safety and enhances voice quality. Furthermore, expiratory muscle training targets the strengthening of the muscles involved in expiration, leading to improvements in respiratory variables [5, 6].

2. Functional respiratory changes in different phenotypes of MND

The ALS spectrum encompasses various clinical phenotypes, with variations in the degrees of involvement of upper motor neurons (UMNs) and lower motor neurons (LMNs), as well as extramotor manifestations, primarily frontotemporal. In the different phenotypes, respiratory manifestations can vary. In the case of limb-onset alS (appendicular), weakness typically begins in the distal muscles and progresses to the muscles responsible for pulmonary mechanics, resulting in alveolar hypoventilation and respiratory failure [7]. In contrast, bulbar-onset alS involves early engagement of the respiratory muscles, especially the diaphragm, leading to a rapid decrease in lung volumes, such as tidal volume (TV) and VC, culminating in hypercapnia and respiratory failure (**Figure 1**) [8].

The weakness resulting from the degeneration of LMNs underlying ALS leads to a reduction in the ability to generate intrathoracic pressure, decreased chest expansion during inhalation, and diminished elastic recoil forces during exhalation. The involvement of UMNs in ALS causes rigidity of the chest wall, increasing resistance and limiting the range of motion, which functionally elevates the mechanical forces required to maintain adequate ventilation. In addition, the reduction in speed, range of motion, and weakness of the respiratory, laryngeal, and bulbar systems further affects the ability to clear the airways in individuals with ALS. Clinically, this manifests as difficulties in managing secretions, airway defense, and the effective expulsion of tracheal contents [8].

Respiratory manifestations, regardless of the phenotype, include exacerbated dyspnea during exertion and at rest, orthopnea, sleep-related breathing disorders,

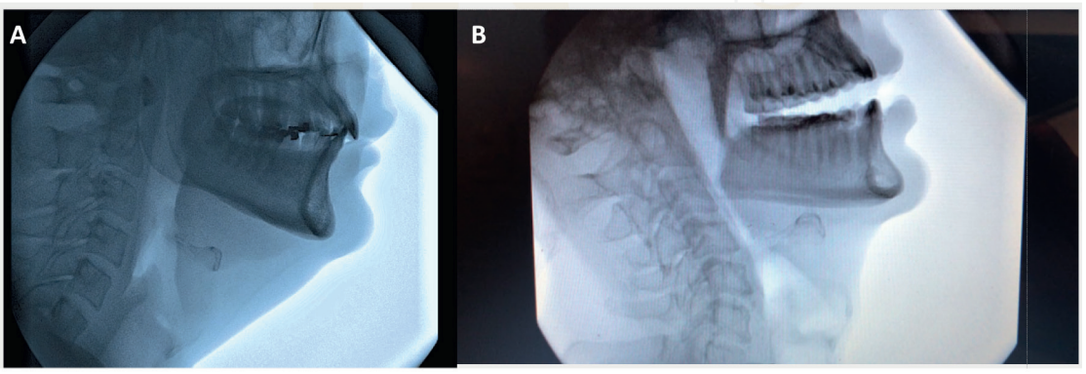

Figure 1.
Videofluoroscopy at rest of individuals with ALS. A: Individual with limb-onset (appendicular) ALS, 89% forced vital capacity; B: Individual with bulbar-onset alS, 12% forced vital capacity. Source: personal collection.

and weakness of the expiratory muscles, which compromises the ability to cough and clear secretions. Using accessory muscles for breathing and paradoxical breathing are typical clinical signs observed during disease progression [9].

3. An overview of respiratory changes and their consequences

3.1 Functional respiratory changes in ALS

In ALS, functional respiratory changes are one of the most critical manifestations of the disease, directly impacting patients' quality of life and survival. The progressive weakness of the respiratory muscles, including the diaphragm, is central to pulmonary function deterioration, resulting in a series of respiratory complications that eventually lead to respiratory failure, the primary cause of death among patients with ALS [9].

Initially, diaphragm weakness compromises thoracic excursion and forced vital capacity (FVC), one of the primary parameters used to monitor respiratory function. The diaphragm, which is responsible for most inspiration, when weakened, limits the expansion of the thoracic cavity, resulting in decreased lung volumes. As the disease advances, accessory respiratory muscles, including the intercostals and neck muscles, may become increasingly engaged. However, this compensation is temporary and insufficient to maintain adequate ventilation in the long term [10].

As diaphragmatic dysfunction worsens, the phenomenon of paradoxical abdominal movement is observed, where, during inhalation, the dysfunctional diaphragm is drawn inward into the thoracic cavity instead of moving downward. This clinical sign indicates severe respiratory weakness and is associated with a significant reduction in FVC and thoracic excursion. The resulting hypoventilation leads to hypercapnia and hypoxemia, exacerbating the sensation of dyspnea, especially during sleep, and increasing the risk of complications such as aspiration pneumonia and lung infections, including pneumonia [1].

Assessing pulmonary function is essential from the first signs of muscle weakness in patients with ALS. Measurements such as FVC and slow vital capacity (SVC) are used to predict the progression of respiratory dysfunction and survival. Studies show that FVC, especially when measured in the supine position, is a sensitive marker for detecting early diaphragmatic weakness. Moreover, SVC has proven to be an important predictor of survival and is correlated with disease progression, particularly in patients with bulbar onset or respiratory involvement [11].

The progression of respiratory weakness in ALS not only worsens dyspnea and exercise intolerance but also interferes with the ability to cough and clear secretions, increasing the risk of severe respiratory infections. Respiratory failure, made worse by diaphragmatic dysfunction and weakness of the accessory muscles, becomes a medical emergency as the disease advances, requiring interventions such as NIV or, in more severe cases, tracheostomy [11].

Early and continuous assessment of respiratory function is fundamental for effective disease management, helping to improve patients' quality of life and survival. By understanding how to manage these complexities, more targeted and effective therapeutic approaches can be developed, providing more humanized care focusing on the specific needs of each ALS patient [12].

Respiratory changes associated with disease progression can cause impairment of the upper airways, including the pharynx, larynx, and oral cavity. These are

critical components for speech and swallowing. These processes depend on the complex coordination of various muscle groups, many of which are controlled by motor neurons that are progressively affected in ALS. Motor neuron degeneration results in muscle weakness, dysarthria (difficulty articulating speech), and dysphagia (difficulty swallowing) [12].

Dysarthria in patients with ALS occurs due to muscle weakness responsible for articulation, such as the tongue, lips, and soft palate. Speech production involves precise coordination between breathing and the muscle movements of the oral cavity, pharynx, and larynx. As ALS progresses, the ability to control these muscles diminishes, resulting in slurred, nasal, or unintelligible speech. Impairment of subglottic pressure, which is essential for voice modulation, further exacerbates these difficulties [11].

Dysphagia in ALS is a consequence of weakness in the muscles involved in swallowing, such as the tongue, pharyngeal, and esophageal muscles. Swallowing is a reflex process that involves multiple phases, including the oral, pharyngeal, and esophageal phases. Muscle weakness leads to difficulty initiating swallowing, reduces the effectiveness of food transport, and increases the risk of aspiration. Aspiration occurs when food or liquids enter the airways instead of going into the esophagus, heightening the risk of aspiration pneumonia, which is a common cause of mortality in patients with ALS [13].

These factors contribute to the overall decline in health and may accelerate disease progression. Speech impairment and swallowing are also directly related to the ventilatory pattern of patients. Studies indicate that the weakness of respiratory muscles, characteristic of ALS, reduces FVC and TV, negatively affecting the ability to speak and swallow. As the disease progresses, respiratory failure becomes a predominant concern, requiring interventions such as NIV, postural techniques, for instance leaning the head forward while swallowing, and modifications in food consistency to reduce the risk of aspiration [13].

4. Coughing and the need for strength in the laryngeal and respiratory muscles

Coughing is a fundamental defense mechanism of the respiratory system, designed to protect the airways from excessive secretions, irritants, and foreign bodies. To be effective, coughing depends on the precise coordination of the respiratory and laryngeal muscles [14]. This section explores the physiology of coughing, emphasizing the critical need for adequate muscular strength to ensure its efficacy, particularly in conditions such as ALS, where muscle weakness significantly compromises this vital function.

4.1 Physiology of coughing

Coughing is a reflex response that can be voluntary or involuntary, initiated by stimuli in the airway receptors. The coughing process can be divided into three main phases (**Figure 2**) [14]:

1. *Inspiratory phase*: this begins with a deep inhalation, increasing lung volume and preparing the respiratory system to generate the pressure needed for expulsion.

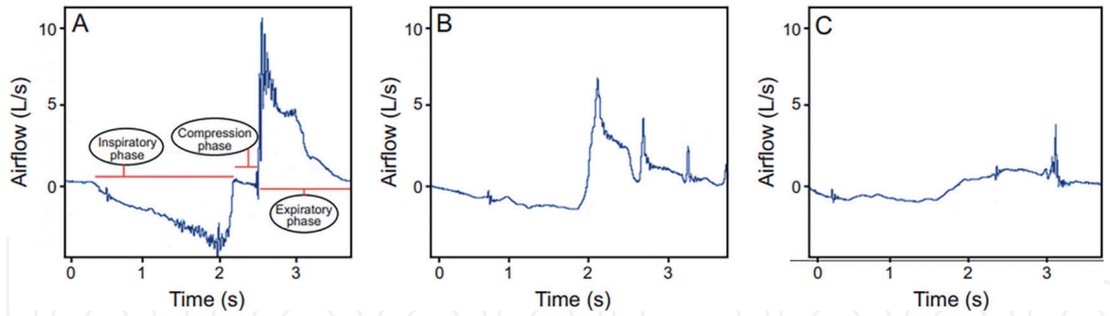

Figure 2.
Representation of spirometry during voluntary coughing.

2. *Compressive phase*: the glottis closes briefly to allow an increase in intrathoracic pressure.

3. *Expulsive phase*: the abrupt opening of the glottis results in an explosive expulsion of air from the lungs, carrying away secretions or irritating particles. The speed and flow of the expiratory air are crucial for the effectiveness of the cough, which is directly influenced by the strength of the muscles involved.

Spirometry waveform during voluntary coughing representing A: cough flow with distinct inspiratory and expiratory parameters in a healthy individual, illustrating the three phases of coughing from which the objective temporal airflow parameters are computed and aberrant. Cough flow in two individuals with ALS: B: spinal onset and C: bulbar onset. Source: Adapted from Andersen et al. [14].

The laryngeal muscles play a central role in modulating airflow during coughing. During the compressive phase, the larynx needs to quickly close the glottis to allow for the accumulation of intrathoracic pressure. This requires efficient contraction of the laryngeal muscles, such as the cricothyroid, which adjusts the tension of the vocal cords, and the thyroarytenoid, which controls glottic closure [15].

The strength of the laryngeal muscles is crucial for achieving a rapid and effective glottal closure. Any impairment in the function of these muscles, as seen in neuromuscular diseases (NMDs), can lead to inadequate glottal closure, resulting in a weak cough that is unable to effectively expel material from the airways. The respiratory muscles, including the diaphragm, intercostals, and abdominals, are responsible for generating the necessary pressure for the expulsive phase of the cough. These muscles must contract with sufficient force to increase intrathoracic pressure, which is the driving force behind the expiratory airflow during coughing [15].

4.2 Impact of muscle weakness on cough

The weakness of the laryngeal and respiratory muscles compromises all aspects of coughing. In patients with ALS, motor neuron degeneration results in the progressive weakness of these muscles, which manifests as a weak and ineffective cough. The inability to generate adequate expiratory airflow means that patients cannot clear secretions from the airways, increasing the risk of pulmonary infections and asphyxiation [16].

Weakness in coughing can lead to severe complications, including recurrent pneumonia and atelectasis (lung collapse), which are common in individuals with ALS. The ineffectiveness of coughing also contributes to the retention of carbon dioxide (hypercapnia) and hypoxia, further exacerbating respiratory failure [16].

4.3 Strategies to improve muscle strength and coughing

Considering the critical role of the laryngeal and respiratory muscles in coughing, several strategies can be implemented to improve cough effectiveness in patients with muscle weakness [13]:

1. *Respiratory exercises*: targeted exercises to strengthen the laryngeal and respiratory muscles can be implemented. Therapy may include diaphragmatic breathing techniques, respiratory resistance exercises, and specific training for the laryngeal muscles [13].

2. *Cough assistance*: cough assistance devices, such as mechanical insufflation-exsufflation devices, can be used to help patients who cannot generate an effective cough on their own. These devices apply positive pressure to the airways during inspiration and negative pressure during expiration, simulating the cough process and helping to clear secretions.

3. *Noninvasive ventilation (NIV)*: NIV can be used to improve ventilation and intrathoracic pressure, facilitating a more effective cough. In some cases, it may be combined with cough assistance to maximize secretion clearance.

4. *Breath stacking*: this technique involves introducing successive volumes of air into the lungs before attempting a cough, thereby increasing the total lung volume and the intrathoracic pressure available for expulsion during coughing.

5. Expiratory muscle training (EMT) to improve coughing in ALS

EMT is a promising intervention to improve expiratory function by increasing the subglottic pressure necessary for effective coughing and airway protection. It focuses on strengthening the muscles responsible for expiration, such as the abdominal and intercostal muscles, generating higher expiratory pressures. In individuals with ALS, weakness of these muscles can lead to ineffective coughing, increasing the risk of respiratory complications [17].

Clinical studies have shown that EMT is a viable and effective intervention for improving respiratory function in ALS. In a study conducted by Plowman et al. [17], the feasibility and impact of EMT on expiratory force generation capacity, swallowing kinematics, cough physiology, and airway protection were evaluated in individuals with ALS. The results indicated that EMT was safe and well-tolerated and led to immediate improvements in expiratory force and hyoid movement during swallowing. The hyoid movement is a crucial event in swallowing, as it facilitates the relaxation and opening of the upper esophageal sphincter, allowing the effective transit of the food bolus from the pharynx to the esophagus and reducing the risk of aspiration.

Another study conducted by Plowman et al. [18] investigated the effect of a 5-week EMT program in individuals with ALS and found significant improvements

in respiratory and bulbar function. Although there were no statistically significant differences in cough spirometry measurements, the 22% reduction in the inspiratory phase suggests a clinical improvement in the ability to inflate the lungs efficiently and in glottic closure, both of which are essential for producing an effective cough.

5.1 EMT techniques to improve outcomes

EMT can be complemented by other respiratory techniques, such as breath stacking. This technique involves accumulating successive volumes of air in the lungs before attempting to cough, thereby increasing the inspired volume and, consequently, the peak cough flow. The increase in inspired volume can enhance the effectiveness of EMT, helping clear secretions and prevent atelectasis. Furthermore, combining EMT with inspiratory muscle training can provide a more comprehensive approach to respiratory rehabilitation in patients with ALS, improving both expiratory and inspiratory pressures, resulting in a more robust overall respiratory function.

Maintaining the ability to generate adequate subglottic pressure is vital for the quality of life of patients with ALS. A study by Plowman et al. [18] demonstrated that EMT, when performed over 12 weeks, had a positive impact on specific respiratory capacity and airway clearance functions during the early stages of ALS. These results suggest that EMT not only improves respiratory function but may also have a positive effect on patient survival.

Although EMT has shown promising results, further research is needed to determine the optimal training intensity, resistance load specifications, and potential long-term benefits. Further studies are needed to explore how combining EMT with other respiratory techniques, such as breath stacking, can optimize clinical outcomes [19].

The rapid progression of ALS and the variation in treatment response among individuals highlight the importance of personalizing therapeutic interventions. Integrating EMT into a comprehensive respiratory rehabilitation plan can provide significant benefits for patients, helping to preserve respiratory function and prolong survival.

6. Volumetric recruitment and impact on the upper airway

Forced expiration plays a crucial role in clearing the lungs, trachea, and larynx. Throat clearing involves the closure of the supraglottic folds, effectively moving material from the laryngeal vestibule to the pharynx. The hawking technique involves a rapid exhalation combined with the soft palate making contact with the base of the tongue. This action is used to move material from the oropharynx to the front of the mouth. Furthermore, postswallowing is an important airway protection behavior, preventing the entry of fluids, food, or secretions into the larynx and lungs.

The supraglottic swallowing maneuver aims for the voluntary closure of the vocal folds before and during swallowing, causing the arytenoid cartilage to tilt toward the base of the epiglottis. This technique is especially recommended to improve two of the most common swallowing challenges faced by people with ALS [20].

Clinical guidelines recommend daily pulmonary volume recruitment (PVR) therapy to combat the decline in lung volume through assisted inflation [21]. PVR is a technique often used by individuals with NMDs to achieve higher lung volumes and improve coughing. This technique involves providing consecutive “breaths” with

Figure 3.
Individual performing pulmonary volume recruitment. Source: Personal archive (authorized by the individual).

inspiratory pressure to the airways, using a manual self-inflating bag, with or without a unidirectional valve, connected to an oronasal mask or mouthpiece (**Figure 3**). The assisted breaths accumulate, resulting in a greater pulmonary inflation volume than can be achieved with spontaneous breathing. Previous research has shown that PVR increases maximum inspiratory capacity (MIC) or pulmonary inflation capacity (PIC), as well as the peak expiratory flow during the maneuver. Retrospective and cohort studies in NMDs suggest that PVR may slow lung function decline [21].

The PVR, also known as breath stacking, is a simple, low-cost manual inflation technique that enhances coughing. Breath stacking maneuvers are essential for maintaining lung capacity and facilitating expulsion in patients with neuromuscular disorders, especially in children [22]. In adults, using an inflation bag with a unidirectional valve increases lung volume. In ALS, breath stacking and MIC are fundamental methods for improving cough effectiveness and providing muscular rest [23, 24]. These techniques rely on good muscular strength in the oropharynx, glottis, and larynx [22].

Although progressive muscle weakness is a central characteristic of ALS, using strength-focused interventions has historically been discouraged due to the concern of muscle overload, which could accelerate physical decline. Traditionally, treatment models for ALS have been primarily palliative in nature. However, recent evidence indicates that light to moderate exercise programs, started early, can enhance physiological capacity and strength, prevent disuse atrophy and deconditioning, as well as alleviate pain and spasticity, and improve the overall psychological well-being of individuals with ALS [25].

7. Perspectives on muscle training in neuromuscular diseases

Integrating expiratory muscle training (EMT) with other respiratory rehabilitation strategies can maximize clinical benefits, providing a valuable intervention to improve respiratory function and survival in ALS. Studies [26, 27] on respiratory

muscle strength training interventions in individuals with ALS have shown transient improvements in inspiratory and expiratory pressures, although long-term effects are still inconclusive. Plowman [28] observed that these interventions resulted in transient gains in variables such as maximum inspiratory pressures and respiratory benefits on the Amyotrophic Lateral Sclerosis Functional Rating Scale (ALSFRS), but the effects were not considered significant.

Clinical trials [27, 28] demonstrate that inspiratory and expiratory muscle strength training programs can extend survival by up to 14 months and improve respiratory and bulbar function, serving as potential prognostic indicators of survival. However, the need for control groups and further investigation is crucial to validate these hypotheses.

Techniques such as breath stacking and EMT have proven viable, safe, and beneficial in enhancing expiratory force generation, swallowing function, and airway protection, especially in early stages of ALS [17]. Moreover, increased inspired volume through breath stacking can lead to improvements in both reflexive and voluntary cough, aiding in mucus clearance and preventing atelectasis.

The recent study by Plowman et al. [19] suggests that respiratory training interventions may positively impact the physiological capacity of respiration and airway clearance function in the early stages of the disease. However, they emphasize the need for additional studies to determine the ideal intensity and long-term benefits. Short-duration training, such as the 8-week protocol applied by Tabor et al. [6], also demonstrated promising results, including increased peak cough flow and expiratory muscle strength.

In 2020, Dorça et al. [29] conducted a pilot study involving 8 patients with ALS who followed a set of techniques combining pulmonary recruitment with expiratory resistance exercise, called respiratory readaptation and reorganization therapy (TR3). This therapy consists of a series of three respiratory exercises, including maximum lung inflation using an inflation bag (pulmonary recruitment) and slow, gradual expiratory muscle training (endurance training). The study described the technique and demonstrated its impact on the airway during its execution. A notable aspect of the study was the innovative use of videofluoroscopy to demonstrate the techniques (**Figure 4**).

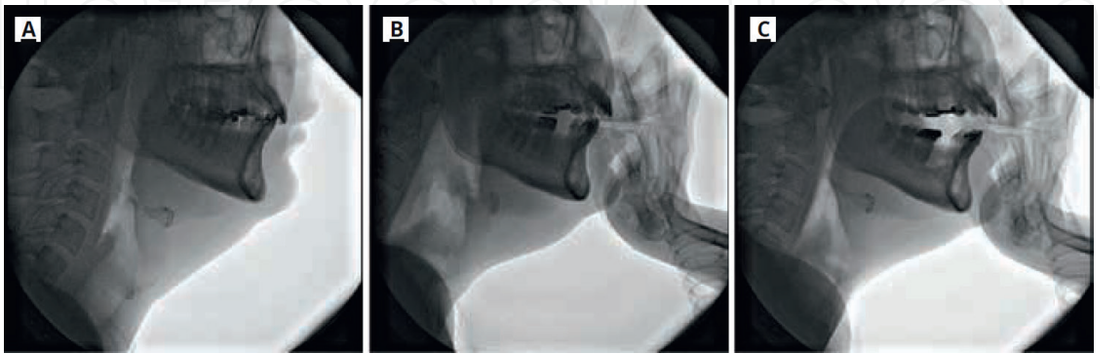

Figure 4.
Impact of Volumetric Recruitment against Expiratory Resistance. Details of the main videofluoroscopic photos of interest analyzed. Overview of the differences in the pharyngeal constriction area during rest and during respiratory training. A. Resting position showing measurements of the pharyngeal area; B. Example of maximum pharyngeal expansion (MPE) during the technique with positive unidirectional pressure valve (PUPV); C. Maximum pharyngeal constriction (MPC) during the PUPV technique. Source: Dorça et al. [29].

8. Conclusion

Understanding the factors related to respiratory dysfunction in NMDs, specifically ALS, is essential for prescribing individualized therapeutic approaches aimed at slowing the progression of the disease. EMT is a systematic technique with promising prospects for exercise prescriptions in this population. However, studies with more robust methodologies, such as clinical trials and control groups, are required for a better understanding of the effects of this therapy and its impact on NMDs.

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