Phrenic Nerve Paralysis: Effects on Diaphragm Mobility

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ABSTRACT

Phrenic nerve paralysis is a severe clinical condition with significant repercussions on respiratory mechanics and patient quality of life. It results from the interruption of diaphragmatic innervation, compromising the physiology of the muscle, reducing pulmonary expansion, and leading to alveolar hypoventilation. The phrenic nerve originates from the cervical roots C3 to C5, following a complex anatomical pathway that makes it vulnerable to iatrogenic injury during cervical or thoracic surgeries or anesthetic blocks. This study reviewed scientific evidence from the past decade, without language restrictions, using databases such as PubMed and SciELO and search terms including "phrenic nerve paralysis," "iatrogenesis," and "neurotization." The analysis integrated data from prospective studies and systematic reviews, highlighting diagnostic techniques such as dynamic ultrasonography and electroneuro- myography.

Keywords: denervation, atrophy, fibrosis, hypoventilation, and neurostimulation.

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ABSTRACT

Phrenic nerve paralysis is a severe clinical condition with significant repercussions on respiratory mechanics and patient quality of life. It results from the interruption of diaphragmatic innervation, compromising the physiology of the muscle, reducing pulmonary expansion, and leading to alveolar hypoventilation. The phrenic nerve originates from the cervical roots C3 to C5, following a complex anatomical pathway that makes it vulnerable to iatrogenic injury during cervical or thoracic surgeries or anesthetic blocks. This study reviewed scientific evidence from the past decade, without language restrictions, using databases such as PubMed and SciELO and search terms including "phrenic nerve paralysis," "iatrogenesis," and "neurotization." The analysis integrated data from prospective studies and systematic reviews, highlighting diagnostic techniques such as dynamic ultrasonography and electroneuromyography. Therapeutic strategies ranged from conservative approaches to surgical interventions, including neurotization with autologous grafts and diaphragmatic plication. The findings conclude that preventing iatrogenic injuries requires standardized protocols, intraoperative monitoring, and equitable access to therapies. These measures are essential to reduce morbidity and mortality and improve clinical outcomes, particularly in vulnerable populations such as the elderly and patients with neuromuscular comorbidities.

Keywords: denervation, atrophy, fibrosis, hypoventilation, and neurostimulation.

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I. INTRODUCTION

Phrenic nerve paralysis is a serious clinical condition with systemic repercussions on the patient's health[1] . It results from the interruption of diaphragmatic innervation, severely affecting respiratory mechanics and compromising the physiological contraction of the diaphragm, which prevents its ideal flattening and, consequently, decreases lung expansion[2].

The phrenic nerve is a mixed nerve, usually originating from the cervical roots C3, C4, and C5 [3,4]. However, in some cases, there are anatomical variations in its origin or path, which considerably increases the risk of surgical iatrogenesis in the absence of preoperative imaging studies[4].

Its path begins at the neck, descending anteriorly to the anterior scalene muscle and posteriorly to the internal jugular vein and subclavian artery[3,4]. Upon crossing the mediastinum, it branches to innervate both hemidiaphragms, synchronizing their contractions during inspiration[4].

It is important to note that there is anatomical asymmetry between the right and left sides: on the right, the nerve accompanies the superior vena cava and the right atrium[5]. In some cases, the proximity of the nerve to the subclavian vein increases the risk of injury during venous procedures in the region[4]. On the left side, it crosses the aortic arch and continues over the left ventricle[5]. This relationship explains the incidence

of postoperative phrenic paralysis in cardiac surgery[9].

This superficial and complex path exposes the nerve to iatrogenic trauma, especially during cervical, thoracic, or cardiac surgery[9]. Interscalene brachial plexus blocks are associated with 15.4% transient diaphragmatic paralysis[10]. Other causes include compression by mediastinal neoplasia's and neuromuscular diseases, such as amyotrophic lateral sclerosis[7]. Rare cases, such as granulomatosis with polyangiitis, may also manifest with phrenic paralysis as an initial symptom[6].

Anatomically, the diaphragm acts as a dynamic barrier between the thoracic and abdominal cavities, being the main motor of respiration[5]. The exclusive innervation of the diaphragm by the phrenic nerve highlights the interdependence between neural structure and muscle function[5]. When this connection is interrupted, the balance of intrathoracic and abdominal pressures is disturbed, resulting in alveolar hypoventilation and dyspnea[8].

These changes can be evidenced by imaging tests, such as X-rays and ultrasounds, which reveal unilateral or bilateral elevation of the diaphragm and reduced respiratory excursion These changes can be evidenced by imaging tests, such as X-rays and ultrasounds, which reveal unilateral or bilateral elevation of the diaphragm and reduced respiratory excursion[8]. Clinically, a paradoxical movement is observed, in which the affected diaphragm is elevated during inspiration, exacerbating hypoxia[1,8].

Therapeutic management varies according to etiology and severity. Conservative strategies include respiratory physiotherapy and non-invasive ventilation in most cases[1,4]. In acute traumatic injuries, neurotization with autologous grafts is indicated, achieving functional recovery in half of patients over the course of one year[11]. Techniques such as diaphragmatic stimulation are a promising therapeutic option in bilateral paralysis, although their high cost limits their accessibility[11,13,14].

This study aims to integrate current evidence on phrenic nerve injury, addressing two fundamental axes. First, the correlation between anatomical variations and risk of iatrogenesis. Second, we evaluate diagnostic methods with an emphasis on their clinical applicability and accuracy.

II. MATERIALS AND METHODS

The bibliographic method was used to collect scientific data from the last five years from medical sources in Portuguese, Spanish, and English, using the following platforms: SciELO, Google Scholar, and PubMed. Keywords such as 'Denervation,' 'Atrophy,' 'Fibrosis,' 'Hypoventilation,' and 'Neurostimulation' were searched. The study included a comparative table addressing the main causes of paralysis, anatomical alterations, histological changes and the associated functional impact.

Classical reference works were also consulted, such as Gray's Anatomy (Gray H. et al., 42nd ed., Elsevier, 2020), Ross MH, Pawlina W. Histology: Text and Atlas. 8th ed. Barcelona: Wolters Kluwer; 2023. and Clinical Embryology (Moore KL., 11th ed., Elsevier, 2021). In addition, guidelines from the American Thoracic Society (ATS) and studies from the National Institutes of Health (NIH) on nerve regeneration were included.

III. RESULTS

The review revealed findings consistent with the literature and medical epidemiology. It provides a systematic overview of cases of phrenic nerve injuries. Such injuries directly compromise diaphragmatic dynamics, resulting in physiological and systemic dysfunctions. Table 1 summarizes crucial data from the main studies, highlighting the type of study, sample, etiology of the injury, and clinical outcome.

Table 1: Phrenic Nerve Paralysis: Comparative Summary of Clinical Studies

Author/Year	Type of Study	Sample	Etiology of the Injury	Clinical Outcome
Saba-Santiago et al. (2022)[10]	Prospective	78 patients	Interscalene block of the brachial plexus	Spontaneous recovery in most cases
Hu et al. (2024)[9]	Integrative review	Data from 107 references	Surgical procedures (cardiac/thoracic)	Reduction of complications with intraoperative monitoring
Boussuges et al. (2020)[8]	Systematic review	Data from 102 references	Diaphragmatic dysfunction	Accurate diagnosis via dynamic ultrasound
Supra & Agrawal (2023)[11]	Narrative review	Data from 94 references	Traumatic injury to the phrenic nerve	Moderate success of nerve grafts
Dubé et al. (2016)[13]	Clinical review	65 surgical cases	Irreversible chronic paralysis	Symptomatic improvement after plicature

Prospective data, such as those from Saba-Santiago et al, highlighted that 15.4% of interscalene blocks resulted in transient diaphragmatic paralysis, with spontaneous resolution in most cases[10]. On the other hand, cardiothoracic surgical interventions, analysed by Hu et al, showed a reduction in complications when accompanied by intraoperative monitoring, reinforcing the importance of preventive strategies[9].

In addition, advanced ultrasound techniques, such as speckle tracking, allow for more accurate assessment of diaphragmatic micro-movements compared to conventional ultrasound[15]. This approach is particularly useful in the early detection of subclinical dysfunctions, such as in patients with chronic comorbidities that predispose them to diaphragmatic weakness[16].

As for therapeutic options, autologous nerve grafts, reviewed by Supra & Agrawal, achieved functional success in 50% of cases, but with heterogeneity in the evaluation criteria between studies[11].

At the same time, electroneuromyography of the phrenic nerve, performed with electrical stimuli near the C3-C5 roots and intramuscular recording in the diaphragm, allows parameters such as latency and amplitude of the muscle action potential to be quantified[18].

Additionally, esophageal manometry assists in the assessment of transdiaphragmatic pressure, whose optimal difference (≥10 cmH_2O) reflects preserved function[17,19]. These findings corroborate the central hypothesis of the study, the complexity and anatomical variability of the phrenic nerve.

IV. DISCUSSION

Phrenic nerve paralysis is not just a technical complication, but a reflection of structural gaps in the safety of routine medical procedures[1]. The incidence of 15.4% of transient paralysis after interscalene block is not merely a statistical fact, but rather an alarming indicator of how anesthetic protocols underestimate the anatomical vulnerability of the nerve[2].

The emphasis on 'spontaneous recovery' in cases of transient paralysis masks an underlying problem, the normalization of iatrogenic risk[2]. Patients may recover diaphragmatic function, but sequelae such as chronic muscle fatigue and exercise intolerance are often overlooked[1]. Studies such as that by Hu et al, which celebrate a 30% reduction in complications with intraoperative monitoring, fail to question why 70% of cases are still exposed to predictable risks [1,9].

The 95% sensitivity of dynamic ultrasound contrasts sharply with the reality of healthcare systems that still rely on static X-rays to assess respiratory dynamics[4,20]. Meanwhile, electro-neuromyography, the gold standard for neuropathies, remains inaccessible in regions without specialists, deepening inequalities in the quality of care[18].

The 50% success rate of nerve grafts is a warning sign: half of patients undergoing invasive procedures are left with functional sequels, often without access to pulmonary rehabilitation or psychological support[19]. Diaphragmatic plication, despite improving symptoms in 80% of cases, is a palliative solution that does not restore respiratory physiology, perpetuating dependence on medical interventions[20].

The ability of bulboprotuberal centers to mask symptoms through accessory muscles is not a physiological detail[22]. While young patients adapt to unilateral dysfunction, elderly patients or those with neuromuscular comorbidities face abrupt decompensation, which is often fatal [23].

V. FINAL CONSIDERATIONS

Phrenic nerve paralysis not only paralyses a muscle, but also chains the body to a silent struggle, where breathing becomes an act of resistance. Those who suffer from it face days marked by constant fatigue, the anguish of not being able to fill their lungs, and the fear that a simple movement will aggravate their weakness. It is a condition that robs them of their most basic autonomy, turning everyday life into a challenge.

However, amid this reality, there is a clear path forward: accurate diagnosis and timely treatment. An ultrasound revealing diaphragmatic elevation, adapted physiotherapy, or a properly placed pacemaker are not just medical procedures, but bridges to the recovery of a full life. Each successful step in managing this disease not only repairs a nerve, but also restores the freedom to breathe without fear.

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