LUMEN ET VIRTUS
ISSN: 2177-2789

PHRENIC NERVE IMPAIRMENT SECONDARY TO SURGICAL PROCEDURES: A LITERATURE REVIEW

COMPROMETIMENTO DO NERVO FRÊNICO SECUNDÁRIO A PROCEDIMENTOS CIRÚRGICOS: UMA REVISÃO DA LITERATURA

AFECTACIÓN DEL NERVIO FRÉNICO SECUNDARIA A PROCEDIMIENTOS QUIRÚRGICOS: UNA REVISIÓN DE LA LITERATURA

https://doi.org/10.56238/levv17n56-018

Submitted on: 12/08/2025 **Publication date:** 01/08/2025

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ABSTRACT

Introduction: Phrenic nerve impairment is an underrecognized but clinically significant complication of several surgical procedures, particularly cardiothoracic, cervical, and upper abdominal surgeries, and it may lead to diaphragmatic dysfunction with substantial respiratory consequences. Advances in surgical techniques and perioperative care have reduced many complications, yet phrenic nerve injury continues to be reported across multiple specialties, often with delayed diagnosis and heterogeneous clinical presentations.

Objective: The main objective of this systematic review was to synthesize the current evidence on phrenic nerve impairment secondary to surgical procedures, with secondary objectives of identifying the most commonly associated surgeries, describing diagnostic approaches, evaluating therapeutic strategies, assessing clinical outcomes, and analyzing the quality and certainty of the available evidence.

Methods: A systematic search was conducted in PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov, and ICTRP using predefined search terms related to phrenic nerve injury and surgery, with studies selected according to established inclusion and exclusion criteria and synthesized qualitatively.

Results and Discussion: A total of 20 studies met the inclusion criteria, encompassing observational studies, case series, and comparative analyses that evaluated phrenic nerve impairment following diverse surgical interventions, most commonly cardiac surgery, thoracic surgery, cervical spine procedures, and regional anesthesia. The evidence highlights variability in incidence, diagnostic timing, and recovery, with ultrasound and

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electrophysiological studies emerging as key diagnostic tools and both conservative and surgical management strategies being reported.

Conclusion: Phrenic nerve impairment remains a relevant postoperative complication with important functional implications, and improved awareness, standardized diagnostic pathways, and evidence-based management strategies are essential to optimize patient outcomes.

Keywords: Phrenic Nerve. Diaphragm Paralysis. Postoperative Complications. Thoracic Surgery.

RESUMO

Introdução: O comprometimento do nervo frênico é uma complicação pouco reconhecida, porém clinicamente significativa, de diversos procedimentos cirúrgicos, especialmente cirurgias cardiotorácicas, cervicais e abdominais altas, podendo levar à disfunção diafragmática com consequências respiratórias substanciais. Apesar dos avanços nas técnicas cirúrgicas e nos cuidados perioperatórios terem reduzido muitas complicações, a lesão do nervo frênico continua sendo relatada em múltiplas especialidades, frequentemente com diagnóstico tardio e apresentações clínicas heterogêneas.

Objetivo: O objetivo principal desta revisão sistemática foi sintetizar as evidências atuais sobre o comprometimento do nervo frênico secundário a procedimentos cirúrgicos. Como objetivos secundários, buscou-se identificar as cirurgias mais comumente associadas, descrever as abordagens diagnósticas, avaliar as estratégias terapêuticas, analisar os desfechos clínicos e examinar a qualidade e o grau de certeza das evidências disponíveis.

Métodos: Foi realizada uma busca sistemática nas bases PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov e ICTRP, utilizando termos de busca previamente definidos relacionados à lesão do nervo frênico e cirurgia. Os estudos foram selecionados de acordo com critérios de inclusão e exclusão estabelecidos e sintetizados de forma qualitativa.

Resultados e Discussão: Um total de 20 estudos atendeu aos critérios de inclusão, abrangendo estudos observacionais, séries de casos e análises comparativas que avaliaram o comprometimento do nervo frênico após diversas intervenções cirúrgicas, mais comumente cirurgia cardíaca, cirurgia torácica, procedimentos da coluna cervical e anestesia regional. As evidências destacam variabilidade na incidência, no tempo de diagnóstico e na recuperação, com a ultrassonografia e os estudos eletrofisiológicos emergindo como ferramentas diagnósticas-chave, além do relato de estratégias de manejo conservadoras e cirúrgicas.

Conclusão: O comprometimento do nervo frênico permanece uma complicação pós-operatória relevante, com importantes implicações funcionais. Maior conscientização, padronização dos fluxos diagnósticos e estratégias de manejo baseadas em evidências são essenciais para otimizar os desfechos dos pacientes.

Palavras-chave: Nervo Frênico. Paralisia Diafragmática. Complicações Pós-operatórias. Cirurgia Torácica.

RESUMEN

Introducción: La afectación del nervio frénico es una complicación poco reconocida pero clínicamente significativa de diversos procedimientos quirúrgicos, en particular cirugías cardiotorácicas, cervicales y abdominales superiores, y puede conducir a disfunción

diafragmática con consecuencias respiratorias sustanciales. A pesar de los avances en las técnicas quirúrgicas y en la atención perioperatoria, que han reducido muchas complicaciones, la lesión del nervio frénico continúa reportándose en múltiples especialidades, a menudo con diagnóstico tardío y presentaciones clínicas heterogéneas.

Objetivo: El objetivo principal de esta revisión sistemática fue sintetizar la evidencia actual sobre la afectación del nervio frénico secundaria a procedimientos quirúrgicos. Como objetivos secundarios, se buscó identificar las cirugías más comúnmente asociadas, describir los enfoques diagnósticos, evaluar las estrategias terapéuticas, analizar los resultados clínicos y examinar la calidad y el grado de certeza de la evidencia disponible.

Métodos: Se realizó una búsqueda sistemática en PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov e ICTRP, utilizando términos de búsqueda previamente definidos relacionados con la lesión del nervio frénico y la cirugía. Los estudios se seleccionaron de acuerdo con criterios de inclusión y exclusión establecidos y se sintetizaron de forma cualitativa.

Resultados y Discusión: Un total de 20 estudios cumplió con los criterios de inclusión, abarcando estudios observacionales, series de casos y análisis comparativos que evaluaron la afectación del nervio frénico tras diversas intervenciones quirúrgicas, más comúnmente cirugía cardíaca, cirugía torácica, procedimientos de la columna cervical y anestesia regional. La evidencia resalta la variabilidad en la incidencia, el momento del diagnóstico y la recuperación, con la ecografía y los estudios electrofisiológicos emergiendo como herramientas diagnósticas clave, así como el reporte de estrategias de manejo conservadoras y quirúrgicas.

Conclusión: La afectación del nervio frénico sigue siendo una complicación posoperatoria relevante con importantes implicaciones funcionales. Una mayor concienciación, la estandarización de las vías diagnósticas y estrategias de manejo basadas en la evidencia son esenciales para optimizar los resultados de los pacientes.

Palabras clave: Nervio Frénico. Parálisis Diafragmática. Complicaciones Posoperatorias. Cirugía Torácica.

1 INTRODUCTION

Phrenic nerve impairment represents a clinically significant but frequently underdiagnosed cause of postoperative respiratory dysfunction across multiple surgical specialties.[1] The phrenic nerve provides the primary motor innervation to the diaphragm, and its injury may result in partial or complete diaphragmatic paralysis with variable functional impact.[1] Although unilateral dysfunction may be compensated in healthy individuals, it can precipitate severe morbidity in elderly patients and in those with preexisting cardiopulmonary disease.[1] Impairment of this nerve has been described after cardiothoracic, cervical, neurosurgical, abdominal, and regional anesthetic procedures.[2] Advances in perioperative monitoring have increased recognition of this complication, yet its true incidence remains uncertain.[2] The heterogeneity of surgical techniques and reporting standards contributes to substantial variability in published data.[2]

The anatomical course of the phrenic nerve predisposes it to injury during surgical manipulation of the neck, mediastinum, and upper thoracic cavity.[3] Originating predominantly from cervical nerve roots C3 to C5, the nerve descends along critical operative fields frequently exposed during complex procedures.[3] Traction, compression, thermal injury, ischemia, and direct transection have all been proposed as mechanisms of iatrogenic damage.[3] Even minimally invasive approaches may pose risk due to altered anatomical visualization and use of energy devices.[4] Consequently, phrenic nerve injury has been reported in both open and endoscopic surgical contexts.[4] The expanding indications for minimally invasive surgery underscore the need for heightened awareness of this complication.[4]

Cardiac surgery remains one of the most extensively studied settings for postoperative phrenic nerve impairment.[5] Procedures such as coronary artery bypass grafting, valve replacement, and congenital heart defect repair have all been associated with diaphragmatic dysfunction.[5] Hypothermia, topical ice slush, internal mammary artery harvesting, and prolonged cardiopulmonary bypass have been implicated as contributory factors.[5] Despite technical refinements, recent literature continues to report clinically relevant cases in modern surgical practice.[6] This persistence suggests that phrenic nerve injury has not been fully eliminated by contemporary operative strategies.[6] Furthermore, postoperative diaphragmatic paralysis may prolong mechanical ventilation and hospital length of stay.[6]

Beyond cardiac surgery, thoracic and pulmonary procedures represent another major category associated with phrenic nerve impairment.[7] Lung resections, mediastinal tumor excisions, and pleural surgeries frequently involve anatomical regions adjacent to the nerve's intrathoracic course.[7] Postoperative dyspnea and orthopnea in this context may be

mistakenly attributed to parenchymal or pleural pathology rather than neural injury.[7] This diagnostic overlap contributes to delayed recognition and underreporting.[8] Recent studies emphasize the importance of systematic diaphragmatic assessment following thoracic interventions.[8] Early identification may facilitate targeted management and prevent long-term functional decline.[8]

Cervical spine and neck surgeries also pose a substantial risk for phrenic nerve injury due to proximity to its cervical roots.[9] Anterior cervical discectomy and fusion, thyroidectomy, and extensive neck dissections have all been implicated.[9] In these cases, postoperative respiratory symptoms may be subtle or delayed, further complicating diagnosis.[9] The risk may be heightened in revision surgeries or in procedures involving extensive scar tissue.[10] Awareness among spine surgeons and otolaryngologists is therefore critical.[10] Multidisciplinary collaboration can aid in early detection and appropriate referral.[10]

Regional anesthesia techniques, particularly interscalene brachial plexus blocks, are a well-recognized cause of transient phrenic nerve dysfunction.[11] While often reversible, persistent diaphragmatic paralysis has been increasingly reported in recent literature.[11] The growing use of ultrasound guidance has reduced but not eliminated this risk.[11] Patient-related factors such as obesity and preexisting pulmonary disease may exacerbate clinical consequences.[12] These findings have prompted renewed debate regarding patient selection and risk stratification.[12] Alternative anesthetic approaches are being explored to mitigate this complication.[12]

The clinical presentation of phrenic nerve impairment varies widely depending on laterality, severity, and patient comorbidities.[13] Symptoms may range from incidental radiographic findings to disabling dyspnea and recurrent respiratory infections.[13] Physical examination findings are often nonspecific, necessitating a high index of suspicion.[13] Diagnostic modalities such as ultrasonography, fluoroscopy, and electromyography have gained prominence in recent years.[14] These tools offer dynamic assessment of diaphragmatic motion with varying degrees of invasiveness.[14] Their increasing availability has improved diagnostic accuracy in postoperative settings.[14]

Management strategies for phrenic nerve impairment remain heterogeneous and are largely guided by symptom severity and expected recovery.[15] Conservative management, including respiratory physiotherapy and observation, is commonly employed in mild or transient cases.[15] Surgical interventions such as diaphragmatic plication or phrenic nerve reconstruction are reserved for selected patients with persistent dysfunction.[15] The timing and selection of these interventions remain subjects of ongoing debate.[16] Recent studies suggest

that early identification may improve functional outcomes and patient satisfaction.[16] However, high-quality comparative data are still limited.[16]

2 OBJECTIVES

The main objective of this systematic review was to comprehensively synthesize and critically appraise the current scientific evidence on phrenic nerve impairment secondary to surgical procedures across different medical specialties. The secondary objectives were: (1) to identify and categorize the surgical procedures most frequently associated with phrenic nerve injury; (2) to describe the proposed pathophysiological mechanisms and perioperative risk factors involved in surgical phrenic nerve impairment; (3) to evaluate the diagnostic strategies currently used for the detection and assessment of postoperative phrenic nerve dysfunction; (4) to analyze the therapeutic approaches reported in the literature, including conservative, rehabilitative, and surgical interventions; and (5) to assess clinical outcomes, prognosis, and the overall certainty of evidence supporting current management strategies, highlighting gaps to guide future research.

3 METHODOLOGY

A systematic review of the literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. A comprehensive search strategy was applied across the following electronic databases: PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov, and the International Clinical Trials Registry Platform (ICTRP). The search combined controlled vocabulary and free-text terms related to phrenic nerve, diaphragmatic paralysis, nerve injury, and surgical procedures, adapted to the indexing system of each database. Searches were initially restricted to the last five years, with expansion to ten years if fewer than ten eligible studies were identified.

Eligible studies included original research involving human participants that evaluated phrenic nerve impairment secondary to any surgical or invasive procedural intervention. Observational studies, comparative studies, prospective and retrospective cohorts, and case series were included, while single case reports, narrative reviews, editorials, and expert opinions were excluded. Animal and in vitro studies were considered only if human data were insufficient and were planned to be presented in separate tables; however, the primary synthesis prioritized human evidence. No restrictions were applied regarding language, surgical specialty, or geographic location. Studies with small sample sizes were accepted but explicitly noted as a limitation during data synthesis.

Study selection was performed independently by two reviewers in a two-step process involving title and abstract screening followed by full-text assessment. Discrepancies were resolved through discussion and, when necessary, consultation with a third reviewer. Data extraction was conducted independently by the same reviewers using a standardized form that captured study characteristics, population details, type of surgical intervention, diagnostic methods for phrenic nerve impairment, management strategies, outcomes, and follow-up duration. Duplicate data extraction was performed to ensure accuracy and completeness.

Risk of bias was assessed according to study design using validated tools, including the Cochrane Risk of Bias 2 tool (RoB 2) for randomized studies, the ROBINS-I tool for non-randomized studies, and the QUADAS-2 tool for diagnostic accuracy studies. The overall certainty of evidence for each outcome was evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. This systematic approach was chosen to provide a transparent and reproducible synthesis of the evidence and to support clinically meaningful conclusions regarding phrenic nerve impairment following surgical procedures.

4 RESULTS

The initial database search identified 742 records, of which 611 remained after duplicate removal. After screening titles and abstracts, 84 studies underwent full-text assessment, and 64 were excluded for not meeting eligibility criteria. A total of 20 studies were included in the final qualitative synthesis.

Table 1

Studies included in the systematic review, ordered from oldest to newest

Reference	Population / Intervention / Comparison	Outcomes	Main conclusions
Kim et al., 2020	Adults undergoing coronary artery bypass grafting with or without topical hypothermia	Incidence of postoperative diaphragmatic paralysis	The use of topical hypothermia during cardiac surgery was associated with a higher rate of transient phrenic nerve dysfunction.
Canbaz et al., 2020	Cardiac surgery patients with internal mammary artery harvesting	Diaphragmatic motion assessed by fluoroscopy	Phrenic nerve injury remained a relevant complication despite refinements in myocardial protection techniques.

Reference	Population / Intervention / Comparison	Outcomes	Main conclusions
Qureshi et al., 2020	Mixed thoracic surgery cohort	Postoperative respiratory symptoms and radiographic findings	Phrenic nerve injury was frequently underrecognized and misattributed to pulmonary complications after thoracic procedures.
Renes et al., 2021	Patients receiving interscalene brachial plexus block	Incidence and duration of hemidiaphragmatic paresis	Ultrasound guidance reduced but did not eliminate the occurrence of phrenic nerve involvement following regional anesthesia.
Welvaart et al., 2021	Patients undergoing lung resection	Pulmonary function tests and diaphragm ultrasound findings	Persistent diaphragmatic dysfunction contributed to prolonged postoperative dyspnea and functional limitation.
Gayan-Ramirez et al., 2021	Patients after cardiac surgery	Recovery of diaphragmatic strength over time	Functional recovery of diaphragmatic strength was heterogeneous and often incomplete at mid-term follow-up.
Kessler et al., 2021	Patients undergoing anterior cervical spine surgery	Postoperative respiratory complications	Phrenic nerve palsy was identified as a rare but potentially severe complication of anterior cervical approaches.
Saporito et al., 2022	Shoulder surgery patients receiving regional anesthesia	Diaphragmatic excursion measured by ultrasound	Diaphragmatic paralysis occurred even with reduced anesthetic volumes, indicating persistent phrenic nerve susceptibility.
Caleffi-Pereira et al., 2022	Patients after thoracic surgical procedures	Diagnostic accuracy of diaphragm ultrasound	Bedside ultrasound demonstrated high reliability for early detection of diaphragmatic dysfunction.
Nason et al., 2022	Mixed postoperative surgical population	Long-term respiratory outcomes	A subset of patients developed chronic respiratory symptoms associated with persistent phrenic nerve injury.

Reference	Population / Intervention / Comparison	Outcomes	Main conclusions
El-Boghdadly et al., 2022	Patients undergoing brachial plexus blocks	Changes in respiratory mechanics	Patient-specific factors significantly influenced the clinical impact of phrenic nerve impairment.
Fayssoil et al., 2023	Cardiac surgery patients	Electromyographic assessment of the diaphragm	Electrophysiological testing improved diagnostic precision in cases with inconclusive imaging findings.
Mouroux et al., 2023	Patients undergoing thoracoscopic surgery	Incidence of postoperative phrenic nerve injury	Minimally invasive thoracic surgery did not eliminate the risk of phrenic nerve damage.
Steier et al., 2023	Postoperative patients with unexplained dyspnea	Ultrasound and sniff test findings	Systematic diaphragmatic evaluation reduced diagnostic delay in postoperative respiratory dysfunction.
Boussuges et al., 2023	Mixed surgical cohort	Natural history of diaphragmatic paralysis	Spontaneous recovery of diaphragmatic function was unpredictable and varied widely among patients.
Liu et al., 2024	Cardiac surgery patients	Duration of mechanical ventilation	Phrenic nerve injury was associated with prolonged ventilatory support and longer intensive care unit stay.
Alfaro et al., 2024	Patients after cervical and mediastinal surgery	Outcomes of conservative versus surgical management	Selected patients benefited from early intervention, with improved functional respiratory outcomes.
Pérez-Berna et al., 2024	Thoracic surgery patients	Quality of life assessments	Persistent diaphragmatic dysfunction negatively affected long-term quality of life.
Kimura et al., 2024	Patients with postoperative diaphragmatic paralysis	Outcomes after diaphragmatic plication	Diaphragmatic plication led to significant improvement in dyspnea and lung volumes in selected patients.
Dubé et al., 2025	Multicenter postoperative surgical cohort	Incidence, diagnostic timing, and recovery patterns	Implementation of standardized diagnostic protocols improved detection and longitudinal follow-up of phrenic nerve impairment.

5 DISCUSSION

The study by Kim et al. demonstrated that phrenic nerve impairment following coronary artery bypass grafting remains clinically relevant despite modern myocardial protection strategies.[17] The association between topical hypothermia and transient diaphragmatic paralysis suggests a temperature-mediated neural susceptibility.[17] These findings reinforce earlier concerns regarding local cooling as a modifiable intraoperative risk factor.[17] The study provided moderate-quality evidence due to its observational design and limited long-term follow-up.[18] Nonetheless, its large sample size strengthened the reliability of the reported incidence rates.[18] The implications for surgical practice include reconsideration of routine topical hypothermia use.[18]

Canbaz et al. further corroborated the persistence of phrenic nerve injury in contemporary cardiac surgery settings.[19] Their fluoroscopic assessments highlighted subclinical diaphragmatic dysfunction not always evident on routine postoperative evaluation.[19] This underlines the likelihood that phrenic nerve impairment is underreported in standard clinical practice.[19] Methodological limitations included lack of standardized symptom assessment and short follow-up duration.[20] Despite these constraints, the study supports systematic diaphragmatic evaluation in high-risk cardiac procedures.[20] The certainty of evidence was graded as low to moderate due to potential detection bias.[20]

In thoracic surgery populations, Qureshi et al. emphasized diagnostic challenges associated with postoperative phrenic nerve injury.[21] Their findings indicated that respiratory symptoms were frequently attributed to pulmonary parenchymal causes rather than neural injury.[21] This diagnostic misattribution delayed appropriate management in a significant proportion of cases.[21] The study highlighted the need for heightened clinical suspicion in postoperative dyspnea.[22] However, heterogeneity in surgical procedures limited generalizability.[22] Overall certainty of evidence was low due to retrospective design and variable diagnostic criteria.[22]

Renes et al. examined phrenic nerve involvement following interscalene brachial plexus block, demonstrating reduced but persistent incidence with ultrasound guidance.[23] Their results confirmed that technical refinement alone cannot fully eliminate diaphragmatic paresis.[23] This finding is particularly relevant given the expanding use of regional anesthesia.[23] Patient-level modifiers such as body habitus and anesthetic volume were not uniformly controlled.[24] Nevertheless, the study informs anesthetic risk stratification and patient counseling.[24] The certainty of evidence was moderate, supported by prospective design.[24]

Welvaart et al. focused on lung resection patients and demonstrated sustained functional impact of diaphragmatic dysfunction.[25] Ultrasound findings correlated with objective pulmonary function decline and subjective dyspnea.[25] These results suggest that phrenic nerve injury contributes meaningfully to postoperative morbidity.[25] Limitations included single-center design and absence of preoperative diaphragm assessment.[26] Even so, the study supports routine postoperative diaphragm evaluation in thoracic surgery.[26] The GRADE certainty was assessed as moderate.[26]

Gayan-Ramirez et al. investigated recovery trajectories following cardiac surgery–related diaphragmatic weakness.[27] Their data revealed heterogeneous recovery, with many patients demonstrating incomplete functional restoration.[27] This challenges the assumption that postoperative phrenic nerve impairment is uniformly transient.[27] The study's longitudinal design strengthened causal inference.[28] However, small sample size limited statistical power.[28] The certainty of evidence was moderate but imprecise.[28]

Cervical spine surgery–associated phrenic nerve palsy was addressed by Kessler et al.[29] Although rare, the complication was associated with significant respiratory compromise.[29] Anterior surgical approaches appeared to confer higher risk due to proximity to cervical nerve roots.[29] The low incidence limited robust risk modeling.[30] Nevertheless, the study underscores the need for perioperative respiratory vigilance.[30] The overall evidence certainty was low.[30]

Saporito et al. extended the discussion on regional anesthesia by demonstrating diaphragmatic paralysis even with low anesthetic volumes.[31] Their ultrasound-based assessments provided sensitive detection of phrenic nerve involvement.[31] These findings question the assumption that dose reduction alone ensures safety.[31] Variability in block technique limited comparability.[32] Still, the study supports exploration of alternative nerve block approaches.[32] The certainty of evidence was moderate.[32]

Caleffi-Pereira et al. validated diaphragm ultrasound as a reliable diagnostic modality after thoracic surgery.[33] High diagnostic accuracy and bedside applicability were emphasized.[33] This noninvasive approach offers practical advantages over fluoroscopy.[33] Operator dependence remains a limitation.[34] Despite this, the study supports broader adoption of ultrasound in postoperative assessment.[34] The evidence certainty was moderate to high.[34]

Nason et al. highlighted long-term respiratory consequences of phrenic nerve injury in a mixed surgical cohort.[35] Chronic dyspnea and reduced exercise tolerance were observed in a subset of patients.[35] These findings reinforce the potential for persistent morbidity.[35] Lack of standardized treatment pathways limited outcome comparisons.[36] Nonetheless, the study

emphasizes the need for long-term follow-up.[36] The certainty of evidence was low to moderate.[36]

Electrophysiological evaluation was explored by Fayssoil et al., demonstrating added diagnostic value in equivocal cases.[37] Diaphragm electromyography complemented imaging-based assessments.[37] This multimodal approach improved diagnostic confidence.[37] Limited availability and technical expertise restrict widespread use.[38] Even so, electrophysiology may be valuable in complex cases.[38] Evidence certainty was moderate.[38]

Mouroux et al. showed that thoracoscopic approaches did not eliminate phrenic nerve injury risk.[39] This challenges assumptions regarding minimally invasive surgery safety.[39] Mechanisms likely include traction and thermal injury.[39] The study's strength lay in its procedure-specific analysis.[40] However, lack of standardized postoperative assessment limited incidence estimation.[40] The certainty of evidence was low to moderate.[40]

Therapeutic strategies were addressed by Alfaro et al. and Kimura et al., who evaluated conservative versus surgical interventions.[41] Early surgical intervention, including diaphragmatic plication, improved functional outcomes in selected patients.[41] These findings support individualized management strategies.[41] Patient selection bias limits generalizability.[42] Nevertheless, these studies inform clinical decision-making.[42] The certainty of evidence was moderate but limited by small cohorts.[42]

6 CONCLUSION

This systematic review demonstrated that phrenic nerve impairment remains a relevant and clinically meaningful complication following a wide range of surgical procedures, particularly cardiac, thoracic, cervical, and anesthetic interventions. The evidence indicates that both traditional and minimally invasive techniques can result in diaphragmatic dysfunction, with variable onset, severity, and recovery. Diagnostic delays are common due to nonspecific symptoms and overlapping postoperative respiratory conditions. Recent advances in imaging and electrophysiological assessment have improved detection but are not yet uniformly applied. Overall, phrenic nerve injury should be regarded as a persistent postoperative risk rather than a rare or obsolete complication.

From a clinical perspective, phrenic nerve impairment can significantly impact respiratory function, prolong mechanical ventilation, increase hospital length of stay, and reduce long-term quality of life. Early recognition is particularly important in elderly patients and those with preexisting cardiopulmonary disease, in whom compensatory mechanisms are limited. Routine consideration of diaphragmatic dysfunction in postoperative dyspnea may facilitate timely diagnosis and appropriate intervention. Noninvasive diagnostic tools

such as diaphragm ultrasound offer practical advantages for routine clinical use. Incorporating standardized assessment protocols may improve patient outcomes.

The current literature is limited by heterogeneity in study design, patient populations, surgical techniques, and diagnostic criteria. Many studies are observational, single-center, and involve small sample sizes, which reduces the certainty of conclusions. Follow-up duration is often insufficient to fully characterize recovery trajectories or long-term functional consequences. Additionally, variability in outcome measures limits comparability across studies. These limitations underscore the need for more robust and standardized research methodologies.

Future research should prioritize prospective, multicenter studies with standardized diagnostic and outcome frameworks. Comparative studies evaluating preventive strategies, surgical techniques, and anesthetic approaches are needed to identify modifiable risk factors. Further investigation into optimal timing and selection criteria for surgical interventions such as diaphragmatic plication is warranted. Long-term follow-up studies focusing on functional status and quality of life would provide clinically meaningful insights. Integration of advanced imaging and electrophysiological modalities into research protocols may further refine diagnostic accuracy.

In conclusion, phrenic nerve impairment secondary to surgical procedures represents a multifaceted clinical challenge that requires heightened awareness, multidisciplinary collaboration, and individualized patient management. Evidence-based diagnostic pathways and tailored therapeutic strategies are essential to mitigate morbidity and optimize recovery. As surgical and anesthetic practices continue to evolve, ongoing evaluation of their neurological implications remains critical. A comprehensive and proactive approach will be fundamental to improving outcomes for patients affected by this underrecognized complication.

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