Narrative review

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Rehabilitation strategies for abdominal wall reinnervation after intercostal nerve injury: A narrative review

Kian Bagheri[1], Alex Reid[2], Dane N Daley[2], Evert Eriksson[3], Melissa C Kolski[4,5] and Matthew C Sherrier[2]

Abstract

The abdominal wall musculature, including the rectus abdominis, transversus abdominis, and internal and external obliques, is a complex, multifunctional unit essential for trunk stability, postural control, and respiratory function. Injury to the intercostal nerves innervating these muscles, which may occur following rib fractures, thoracic surgery, trauma, or iatrogenic interventions, can lead to significant motor and respiratory deficits, including abdominal wall bulging, reduced trunk stability, impaired cough, and diminished forced expiration. Surgical interventions such as intercostal nerve exploration and neurolysis with possible direct neurorrhaphy versus allograft nerve reconstruction offer the potential for reinnervation; however, successful functional recovery depends on structured, targeted rehabilitation. This narrative review synthesizes current knowledge on abdominal wall anatomy, intercostal nerve injury consequences, surgical repair strategies, and rehabilitation principles, focusing on abdominal wall-specific recovery. It proposes a phased rehabilitation framework that integrates motor retraining, respiratory optimization, cortical plasticity–guided techniques, and functional retraining. Objective outcome measures, including ultrasound, electrodiagnostic testing, and timed leg-lowering tests and respiratory metrics such as peak cough flow, can guide and track recovery. By combining neuroplasticity-driven interventions, respiratory integration, and progressive, task-specific retraining, clinicians may optimize functional outcomes for patients following intercostal nerve injury. Future research should prioritize the standardization of assessment methods and validation of structured rehabilitation protocols.

Keywords

Intercostal nerve injury, abdominal wall denervation, neuroplasticity, respiratory muscle training, peripheral nerve rehabilitation, core stabilization

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Introduction

The abdominal wall is a complex, multilayered structure that provides mechanical stability and supports essential bodily functions. It is composed of the rectus abdominis (RA), external oblique (EO), internal oblique (IO), and transversus abdominis (TrA), which act in combination with the fascia, connective tissue, and diaphragm to form a dynamic cylinder facilitating

[1]Department of Physical Medicine & Rehabilitation, HonorHealth, USA
[2]Department of Orthopaedics and Physical Medicine & Rehabilitation, Medical University of South Carolina, USA
[3]Department of Surgery, Medical University of South Carolina, USA
[4]Department of Physical Therapy and Human Movement Sciences, Feinberg School of Medicine, Northwestern University, USA
[5]Department of Physical Therapy and Human Movement Sciences, Shirley Ryan AbilityLab, USA

Corresponding author:
Kian Bagheri, Department of Physical Medicine and Rehabilitation. 8850 E Pima Center Parkway, Scottsdale, AZ 85258, USA.
Email: kbagheri@honorhealth.com

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trunk stability, movement, and intra-abdominal pressure regulation.[1–4] In addition to enabling trunk flexion, rotation, and stabilization, it contributes to respiration, defecation, micturition, parturition, and protection of intra-abdominal organs.

Mechanisms of intercostal nerve (ICN) injury

ICN injuries occur in diverse settings. Displaced rib fractures may directly damage nerves in the costal groove, whereas surgical stabilization and thoracic procedures pose additional iatrogenic risk.[5–9] Thoracotomy and minimally invasive thoracic procedures can injure nerves via traction or transection during retraction or incision, leading to postoperative pain and abdominal wall dysfunction.[10–13] Tumor resections, chest wall reconstructions, and vascular or plastic surgery procedures involving rib mobilization pose similar risks.

Abdominal wall trauma, including penetrating injuries or high-energy blunt impacts, may directly damage the ICNs or lead to secondary scarring and entrapment. Even lower-grade mechanisms, such as prolonged compression from rib plating or fibrosis following chest tube placement, may result in localized intercostal neuropathy. These diverse etiologies underscore the vulnerability of the ICNs and the need to anticipate their functional consequences.

Clinical sequelae of ICN injury

The clinical manifestations of ICN injury reflect the extent and chronicity of abdominal wall denervation and encompass motor, respiratory, and psychosocial domains. Motor sequelae include asymmetric abdominal wall weakness, visible bulging or pseudohernia, impaired trunk stability, and progressive muscle atrophy over time.[10,13–18] Loss of abdominal muscle strength compromises expiratory force and cough efficacy, increasing susceptibility to mucus retention and respiratory infections. Contour deformities, chronic discomfort, and reduced exercise tolerance also impact body image, quality of life, and functional independence.[19]

Surgical repair and functional recovery

Microsurgical techniques for ICN repair include direct end-to-end repair, allograft nerve reconstruction, autologous nerve grafting (commonly using the sural nerve), and nerve transfers adapted from brachial plexus surgery.[20,21] These interventions aim to restore nerve continuity and promote axonal regeneration with outcomes monitored electrophysiologically or using high-resolution ultrasound.[22,23] Axonal regeneration typically occurs at the rate of 1–3 mm/day, with early reinnervation detectable using electromyography (EMG) or ultrasound before clinical improvement is evident.[24–27]

However, restoration of motor innervation does not guarantee functional recovery. Prolonged denervation causes muscle fibrosis and fatty infiltration, limiting the contractile capacity even after reinnervation.[28–32] Concurrently, cortical motor representations shrink following denervation, requiring targeted rehabilitation to reestablish coordinated voluntary activation and leverage neuroplasticity.[33] Patients must also retrain abdominal wall activation amid altered biomechanics and compensatory movement patterns.

These factors underscore that surgical repair, although necessary under certain conditions, is insufficient in isolation. Rehabilitation likely plays an important role in facilitating the recruitment of reinnervated fibers, preventing maladaptive compensation, and restoring the integration of abdominal wall function with trunk stabilization, posture, and respiration.[34] Functional outcomes depend on time to surgery, nerve graft length, distance to target musculature, surgical technique, and degree of pre-existing atrophy or fibrosis.[22,23] In select patients, combining microsurgical repair with targeted rehabilitation best enables functional recovery.

Current gaps in rehabilitation

To the best of our knowledge, this is the first narrative review to propose a structured, phased rehabilitation framework specifically targeting abdominal wall reinnervation following ICN repair, integrating motor retraining with respiratory function. Despite the recognized importance of rehabilitation after peripheral nerve repair, standardized protocols specific to the abdominal wall remain limited. Existing literature primarily addresses upper and lower extremity nerve injuries where functional outcomes can be measured via strength, dexterity, or gait.[22,23] In contrast, abdominal wall recovery lacks validated outcome measures, and rehabilitation often relies on general core strengthening or respiratory therapy programs.

The absence of standardized approaches risks persistent weakness, maladaptive compensation, and chronic dysfunction and hinders cross-study comparisons and guideline development. There is a critical need for research establishing objective measures of abdominal wall function and evaluating structured, phased rehabilitation programs.

Search strategy

This narrative review was informed by targeted literature searches conducted in August 2025 using PubMed and relevant specialty journals focusing on abdominal wall anatomy, ICN injury, peripheral nerve regeneration, respiratory dysfunction, and neurorehabilitation principles. Search terms included combinations of "intercostal nerve injury," "abdominal wall denervation," "abdominal wall rehabilitation," "peripheral nerve repair," "respiratory muscle training," and "neuroplasticity." Articles were selected based on clinical relevance to abdominal wall reinnervation and rehabilitation concepts, with prioritization of studies describing peripheral nerve regeneration, respiratory function, and functional assessment. Although a formal systematic screening process was not adopted, the selection emphasized clinically translatable findings and concepts applicable to this population. This review was conducted as a narrative review and guided by the Scale for the Assessment of Narrative Review Articles (SANRA).[35]

This narrative review addresses current gaps by summarizing abdominal wall anatomy and function, the sequelae of ICN injury, and neurorehabilitation principles relevant to recovery. We highlighted the dual musculoskeletal and respiratory roles of the abdominal wall, reviewed available objective assessment tools, and propose a phased rehabilitation framework integrating motor retraining, respiratory optimization, and neuroplasticity-guided strategies to guide recovery after ICN repair.

Anatomy and physiology of the abdominal wall

The abdominal wall comprises four paired muscle groups—the RA, EO, IO, and TrA—each contributing to posture, movement, respiration, and intra-abdominal pressure regulation. The RA, oriented vertically, facilitates trunk flexion and assists in generating intra-abdominal pressure. The EO, running inferomedially, and the IO, oriented superomedially, coordinate rotational movements and lateral flexion. The TrA, the deepest of the abdominal muscles, acts as a stabilizing corset, providing segmental spinal support and playing a central role in regulating intra-abdominal pressure.

The abdominal wall musculature receives motor innervation from the ventral rami of ICNs T7-T12, which travel between the IO and TrA and supply the RA and provides cutaneous sensation, with additional contributions from the iliohypogastric and ilioinguinal nerves (L1).[2–4] Because this innervation is segmental, injury to a single ICN can cause localized muscle weakness, whereas multilevel injury can lead to broader impairments in trunk stability and respiratory function. Understanding this segmental distribution is critical for identifying patterns of weakness or dysfunction after ICN injury and guiding targeted rehabilitation.

From a respiratory function standpoint, the abdominal wall is critical during forced expiration, coughing, and sneezing as it generates intra-abdominal pressure to aid ventilation. It contributes significantly to ventilation, expiratory flow, and airway clearance. Recent anatomic studies have demonstrated that ICNs 7, 8, and 9 provide branches directly to the diaphragm.[2] Consequently, abdominal wall dysfunction resulting from ICN injury can impair not only motor performance but also pulmonary health.

Due to the widespread roles and effect of the abdominal wall across multiple physiological domains, including but not limited to motor control and respiration, even partial denervation can result in profound impairment. Therefore, effective rehabilitation following an ICN injury must adopt a broad approach that addresses these diverse functions of the abdominal wall.

Consequences of an ICN injury

An ICN injury results in segmental denervation of the abdominal wall musculature, producing marked structural, functional, and quality of life consequences. Clinically, this manifests as asymmetric abdominal wall contouring, pseudohernia, visible bulging, weakness with trunk flexion and rotation, impaired coordination, and reduced postural stability, which may contribute to compensatory thoracic and/or lumbar spine pain and challenges in lifting, balance, and gait. Functional impairments also extend to activities requiring effective intra-abdominal pressure generation, including coughing, defecation, urination, and heavy lifting, with downstream respiratory and functional implications. In addition, visible deformity and chronic discomfort may lead to psychosocial distress, reduced activity participation, and diminished quality of life. These deficits can be quantified using objective imaging, electrodiagnostic, and functional assessments, which are described in detail below in the Functional Testing and Objective Outcome Measures section.

Functional testing and objective outcome measures

Objective assessment of abdominal wall function is crucial for both clinical care and research. Imaging modalities such as ultrasound can assess the muscle thickness of the TrA, IO, and EO at rest and during contraction. Reliability studies have demonstrated strong intra- and inter-rater agreements, confirming the robustness of ultrasound for longitudinal

monitoring.[36,37] Panoramic imaging allows large field-of-view assessment of the RA, whereas elastography quantifies stiffness and contractile properties. Elastography, particularly shear wave elastography, has been shown to detect alterations in muscle stiffness that correlate with histologic, magnetic resonance imaging (MRI), and functional markers of muscle atrophy across experimental models, inflammatory myopathies, sarcopenia, and neuromuscular disease, supporting its role as a noninvasive tool for assessing muscle degeneration.[38–40]

Electrodiagnostic studies provide complementary data. Needle EMG can identify increased spontaneous activity that confirm denervation, and the appearance of polyphasic motor units signals reinnervation. Electrodiagnostic testing of the ICNs in the setting of rib fractures has demonstrated reliability and utility in diagnosing and localizing lesions.[8]

In the clinical setting, functional tests can capture outcomes relevant to patients. The timed leg-lowering task, in which a patient lowers their extended legs while in the supine position, maintaining posterior pelvic tilt, is sensitive to anterior abdominal wall endurance and control.[41] Core endurance tasks, such as plank holds, provide additional benchmarks.[42] Critically, cough peak flow provides a quantifiable respiratory outcome that reflects the combined contribution of abdominal and thoracic musculature.[43] Clinically, these measures may be collected at baseline and reassessed periodically (early reinnervation and strengthening phases) to guide progression, with imaging and electrodiagnostic tools supporting the detection of reinnervation and functional tests reflecting meaningful clinical change.

Neuroplasticity and guided relearning

Cortical plasticity plays a central role in recovery after peripheral nerve injury. In the absence of input, cortical motor representations of denervated muscles shrink, limiting voluntary recruitment. Targeted interventions can maintain and even expand these representations, priming the brain to recruit newly reinnervated muscle fibers.

Mirror therapy provides visual feedback of movement on the unaffected side, engaging mirror neuron networks and strengthening cortical activation of the injured side. Motor imagery, in which patients mentally rehearse abdominal contractions, and action observation, in which they watch demonstrations of abdominal exercises, also stimulate motor networks without physical contraction. Biofeedback, using surface EMG or real-time ultrasound imaging, offers external confirmation of muscle activity, reinforcing voluntary recruitment once reinnervation begins. Early integration of these strategies primes the nervous system and enhances subsequent strengthening and functional reintegration.

Respiratory integration

The relationship between respiratory function and abdominal wall mechanics warrants focused discussion. The abdominal wall is essential for ventilation and airway clearance, working in concert with the diaphragm to regulate intra-abdominal pressure and optimize respiratory mechanics. During forced expiration, abdominal wall contraction compresses the abdominal cavity, elevates intra-abdominal pressure, and drives the diaphragm upward, thereby enhancing expiratory flow. Abdominal wall tension and the rapid generation of these pressures are essential for ventilatory mechanics, including an effective cough and airway clearance.[1,44,45]

ICN injury is associated with clinically significant respiratory consequences due to impaired abdominal wall recruitment.[8] Resulting expiratory weakness diminishes cough efficacy and forced expiration, compromising airway clearance and increasing the risk of secretion retention, recurrent infections, atelectasis, and pneumonia. These risks are amplified in patients with concomitant pulmonary disease, spinal cord injury (SCI), or neuromuscular disorders, where baseline cough strength is already limited; in such populations, even minor deficits can lead to chronic morbidity and necessitate hospitalization.

Therefore, rehabilitation should directly address expiratory function. Inspiratory and expiratory muscle training with threshold devices has been shown to improve maximal inspiratory and expiratory pressures, enhance lung volumes, and increase cough effectiveness in patients with neuromuscular disease. Cough training through voluntary practice, manual assistance, or resisted expiration, is central in enhancing airway clearance, consistent with broader guidelines of respiratory management in patients with neuromuscular weakness.[6,46] This strategy reinforces abdominal wall activation in a functional context, whereas abdominal weight training further promotes muscle activation. These respiratory-focused strategies not only preserve pulmonary health but also provide task-specific training that accelerates the integration of reinnervated abdominal muscles.[47]

Phased rehabilitation strategy

Rehabilitation after a peripheral nerve injury is commonly conceptualized as a phased process aligned with the stages of reinnervation and functional recovery. Due to the limited literature specifically addressing abdominal wall reinnervation

Table 1. Proposed phased rehabilitation framework following intercostal nerve repair or reconstruction.

Phase	Timeline	Primary goals	Example interventions	Proposed outcome measures
Phase 1: early postoperative/ pre-reinnervation	0–6 weeks	Protect repair, preserve mobility, optimize respiration, and prevent maladaptive compensation	Diaphragmatic breathing, incentive spirometry, postural training, and gentle trunk mobility	Baseline ultrasound, EMG, and respiratory measures
Phase 2: early reinnervation	6 weeks to 6 months	Facilitate cortical recruitment and early activation	Motor imagery, mirror therapy, ultrasound biofeedback, and low-intensity activation exercises	Ultrasound muscle activation and EMG evidence of reinnervation
Phase 3: functional strengthening	6–18 months	Improve strength, endurance, and respiratory integration	Progressive trunk stabilization, resisted exhalation, cough retraining, and leg-lowering tasks	Functional core testing, cough peak flow, and endurance testing
Phase 4: return to function	>18 months	Restore dynamic function and task-specific performance	Advanced core exercises, lifting, gait stabilization, and sport/ work-specific training	Functional testing, respiratory endurance, imaging, and EMG as indicated

EMG: electromyography.

after ICN repair, the framework proposed below is derived primarily from principles established in peripheral nerve rehabilitation, respiratory rehabilitation, neuroplasticity research, and expert clinical opinion. Accordingly, this phased model should be interpreted as a conceptual rehabilitation framework intended to guide clinical decision making and future investigation rather than as a validated protocol (Table 1). Nevertheless, the integration of motor retraining, respiratory mechanics, and neuroplasticity-driven interventions may provide a useful structure for potentially optimizing functional reintegration of reinnervated abdominal musculature.

Phase 1: Early postoperative/pre-reinnervation (0–6 weeks)

The initial phase of rehabilitation focuses on protecting the surgical repair, preserving tissue health, and preventing secondary complications during the period of complete or near-complete denervation. Active contraction of the affected abdominal musculature is not expected at this stage; therefore, the primary goals are maintenance of mobility, prevention of maladaptive postural strategies, and preservation of respiratory and cardiovascular function.

In patients with abdominal wall denervation, early compensatory patterns are common and may include excessive lumbar lordosis, asymmetric trunk loading, and increased reliance on accessory respiratory muscles. If unaddressed, these strategies can become entrenched and persist even after reinnervation. Rehabilitation interventions during this phase emphasize diaphragmatic breathing, incentive spirometry, postural training, gentle trunk mobility, and activation of non-denervated musculature to support trunk stability without overloading the denervated region. Patient education is critical to reinforce movement awareness and establish patient expectations regarding the prolonged timeline of nerve recovery. Baseline assessment using ultrasound, electrodiagnostic testing, and functional measures establishes reference values for longitudinal monitoring.

Phase 2: Early reinnervation (6 weeks to 6 months)

As axonal regeneration progresses and early reinnervation begins, rehabilitation shifts toward facilitating the activation of regenerating motor units and re-engaging cortical motor representations. Newly reinnervated muscle fibers are often weak, poorly coordinated, and difficult to voluntarily recruit. Experimental and clinical studies in limb nerve injury have demonstrated that cortical motor maps shrink after denervation and expand with targeted use, highlighting the importance of neuroplasticity-driven interventions during this phase.[33,48]

Motor imagery, mirror therapy, and biofeedback techniques are employed to enhance cortical engagement before consistent voluntary contraction is present. For the abdominal wall, real-time ultrasound imaging and surface EMG provide visual and tactile feedback that can help patients identify subtle muscle activation and improve recruitment specificity. Low-intensity, isolated activation exercises are introduced cautiously and integrated with controlled breathing to reinforce

appropriate coordination with the diaphragm and pelvic floor. The emphasis during this phase is on quality of activation rather than force generation, with careful avoidance of compensatory activation of adjacent musculature.

Phase 3: Functional strengthening (6–18 months)

With improving voluntary contraction and motor unit recruitment, rehabilitation progresses toward strengthening, endurance development, and functional integration. This phase aligns with ongoing maturation of the reinnervated motor units and improved neuromuscular coordination. Progressive resistance training is introduced in a graded manner, beginning with low-load, controlled exercises and advancing toward tasks that challenge trunk stability and dynamic control.

For abdominal wall rehabilitation, exercises such as controlled trunk flexion and rotation, anti-extension and anti-rotation stabilization tasks, and timed leg-lowering maneuvers are particularly relevant. Importantly, strengthening is integrated with respiratory training, as the abdominal musculature plays a critical role in forced expiration and cough. Interventions such as resisted exhalation, expiratory muscle training, and cough retraining are incorporated to restore effective airway clearance and expiratory force.[49] This phase also emphasizes endurance and coordination, preparing patients for sustained functional activities.

With return of voluntary contraction, rehabilitation emphasizes progressive strengthening and functional integration. Core stabilization drills, trunk rotation, leg-lowering tasks, and dynamic postural challenges are combined with respiratory-focused training such as resisted exhalation and cough retraining. This phase develops endurance and integrates reinnervated muscles into coordinated patterns of trunk stability and breathing.

Phase 4: Return to function (>18 months)

The final phase of rehabilitation focuses on task-specific retraining and return to higher-level function. The goal at this stage is not merely restoration of isolated muscle strength but reintegration of the abdominal wall into complex, coordinated activities that reflect individual functional demands. This may include dynamic postural control, lifting and carrying tasks, gait-related trunk stabilization, and sport- or occupation-specific movements.

Respiratory endurance and cough effectiveness are further refined to support prolonged activity and reduce the risk of pulmonary complications. Advanced core exercises, multiplanar trunk movements, and high-level conditioning are progressively introduced. Ongoing objective assessment remains essential, as residual asymmetries or compensatory strategies may persist and require targeted intervention. Ultrasound imaging, electrodiagnostic testing, functional tests such as timed leg-lowering, and respiratory measures, including cough peak flow, provide complementary data to guide progression and confirm meaningful recovery.

Knowledge gaps and future directions

Despite the clinical importance of abdominal wall reinnervation, significant knowledge gaps remain. Much of the available literature consists of case reports, small case series, extrapolation from extremity peripheral nerve rehabilitation, and studies focused primarily on imaging, electrodiagnostic testing or surgical outcomes rather rehabilitation-specific interventions or functional recovery trajectories. Significant heterogeneity exists across patient populations, injury mechanisms, surgical techniques, timing of intervention, and outcome measures, limiting comparison across studies and preventing the development of evidence-based rehabilitation guidelines. Furthermore, prospective controlled investigations evaluating rehabilitation-specific interventions following ICN repair are currently lacking.

Combining ultrasound, electrodiagnostic testing, timed leg-lowering, and cough peak flow could standardize assessment and improve comparability across studies.[50–54] Future research should employ multicenter prospective trials, given the relative rarity of these cases, and use structured rehabilitation protocols with standardized outcome measures. Randomized studies are particularly needed to evaluate phased rehabilitation strategies, integration of neuroplasticity-driven interventions, and the role of respiratory muscle training. Systematic integration of these approaches will be essential for building an evidence base capable of informing consensus guidelines and standardizing care.

Conclusion

ICN injury with abdominal wall denervation represents a unique and often overlooked neuromuscular challenge that disrupts both motor stability and respiratory mechanics. Although surgical repair may restore the potential for reinnervation, rehabilitation strategies specific to abdominal wall recovery remain poorly defined. Existing evidence derived from peripheral nerve rehabilitation, respiratory muscle training, and neuroplasticity research suggests that a phased and integrated

rehabilitation approach facilitates recovery; however, direct evidence supporting these interventions in abdominal wall reinnervation remains limited.

Accordingly, the rehabilitation framework proposed in this review should be considered a conceptual model intended to guide clinical reasoning and future research rather than an established evidence-based protocol. Prospective multicenter studies using standardized functional, imaging, electrodiagnostic, and respiratory outcome measures are needed to validate rehabilitation strategies and establish consensus guidelines for this underrecognized patient population.

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ORCID iDs

Kian Bagheri https://orcid.org/0000-0003-0303-5949
Evert Eriksson https://orcid.org/0000-0002-4099-325X
Melissa C Kolski https://orcid.org/0000-0002-8341-3171

Author contributions

K.B.: Methodology, literature review, writing—original draft preparation and review, and manuscript editing.
A.R.: Methodology, literature review, and writing—original draft preparation and review.
D.D.: Conceptualization, methodology, and manuscript editing.
E.E.: Conceptualization, methodology, and manuscript editing.
M.K.: Conceptualization, methodology, and manuscript editing.
M.S.: Conceptualization, methodology, writing—original draft preparation and review, manuscript editing, and supervision.
All authors contributed to manuscript revision, read, and approved the submitted version. All authors agree to be accountable for all aspects of the work.

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Data availability statement

All data relevant to this study are included in the article. No additional data are available.

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