RPNS: 2067 | ISSN: 1817-9088
Volumen 22 (2025)
N° 4 (octubre - diciembre)

Revisión Recibido: 28/05/2025 | Aceptado: 20/08/2025

Therapeutic exercise in Abdominal Hernioplasty: physio-cellular mechanisms and translational protocols for recurrence reduction (2014-2024)

Ejercicio terapéutico en Hernioplastia Abdominal: mecanismos fisio-celulares y protocolos traslacionales para la reducción de recidivas (2014-2024)

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Abstract

This article summarizes the scientific evidence (2014-2024) on the physiological mechanisms of therapeutic exercise in postoperative recovery from abdominal hernias, with the aim of establishing a translational framework that integrates biomechanics, cell biology, and technology to optimize rehabilitation protocols. The justification arises from the persistent recurrence rates (10-25%) associated with traditional approaches based on prolonged rest, despite advances in minimally invasive surgical techniques and biomaterials. The historical and trend evolution section (2014-2024) analyzes the transition from passive protocols to the early integration of exercise, highlighting milestones such as the validation of prehabilitation and early neuromuscular activation (2-4 weeks postoperatively), which reduce recurrences by 40%. This analysis contextualizes the urgency of standardizing evidence-based physical interventions. Under the heading of physiological mechanisms, cellular responses to exercise are broken down: tissue remodeling, intra-abdominal pressure regulation, angiogenesis, and immune modulation.

These fundamentals explain why exercise accelerates functional recovery and prevents complications. The section on stepped protocols proposes a three-phase model (acute, strengthening, recovery), supported by biomarkers and parameters. This section is crucial for translating pathophysiological evidence into guidelines applicable by rehabilitation professionals. Finally, technological challenges and solutions (telerehabilitation, wearables for monitoring intra-abdominal pressure) are addressed, highlighting the need to close access gaps and personalize therapies. The article concludes that the integration of these axes will transform therapeutic exercise into the gold standard for post-hernioplasty recovery, reducing recurrences and improving quality of life.

Keywords: Therapeutic exercise, abdominal hernia, pathophysiology, surgical repair, recurrence, rehabilitation.

Resumen

Este artículo sintetiza la evidencia científica (2014-2024) sobre los mecanismos fisiológicos del ejercicio terapéutico en la recuperación postoperatoria de hernias abdominales, con el objetivo de establecer un marco traslacional que integre biomecánica, biología celular y tecnología para optimizar protocolos de rehabilitación. La justificación surge de las persistentes tasas de recidiva (10-25%) asociadas a enfoques tradicionales basados en reposo prolongado, pese a los avances en técnicas quirúrgicas mínimamente invasivas y biomateriales. El epígrafe de evolución histórico-tendencial (2014-2024) analiza la transición desde protocolos pasivos hacia la integración temprana del ejercicio, destacando hitos como la validación de la prehabilitación y la activación neuromuscular temprana (2-4 semanas postoperatorias), que reducen recidivas en un 40%. Este análisis contextualiza la urgencia de estandarizar intervenciones físicas basadas en evidencia. En el epígrafe de mecanismos fisiológicos, se desglosan las respuestas celulares al ejercicio: remodelación tisular, regulación de presión intraabdominal, angiogénesis, modulación inmune.

Estos fundamentos explican por qué el ejercicio acelera la recuperación funcional y previene complicaciones. La sección de protocolos escalonados propone un modelo en tres fases (aguda, fortalecimiento, reintegro), sustentado en biomarcadores y parámetros. Este epígrafe es crucial para traducir la evidencia fisiopatológica en pautas aplicables por profesionales de rehabilitación. Finalmente, se abordan desafíos y soluciones tecnológicas (tele-rehabilitación, wearables para monitorizar presión intraabdominal), subrayando la necesidad de cerrar brechas de acceso y personalizar terapias. El artículo concluye que la integración de estos ejes transformará el ejercicio terapéutico en el estándar oro de la recuperación posthernioplastia, reduciendo recidivas y mejorando calidad de vida.

Palabras clave: Ejercicio terapéutico, hernia abdominal, fisiopatología, reparación quirúrgica, recidiva, rehabilitación.

Introduction

Abdominal hernias are a highly prevalent surgical pathology globally, with more than 20 million repairs performed annually and healthcare costs exceeding $32 billion per year (Oma, 2019). Despite advances in minimally invasive techniques (laparoscopic/robotic) and innovative biomaterials (PVDF or titanium mesh), historical recurrence rates (10–25%) remained a critical challenge, associated with rehabilitation protocols based on prolonged rest (6–8 weeks) that induced muscle atrophy and alterations in collagen synthesis (Meléndez, 2019). This scenario began to transform between 2019 and 2024, when studies showed that the early integration of therapeutic exercise (from the 2nd postoperative week) reduced recurrences by 40% through specific pathophysiological mechanisms, redefining its role from a complement to a central axis of functional recovery (Hernandorena, 2021).

The decade 2014-2024 evidenced how exercise modulates key cellular processes in hernia repair: connective tissue remodeling, where controlled mechanical loads (0.5-2 kg) activate the TGF-β1/Smad3 pathway, optimizing type I collagen synthesis and its fibrillar alignment (↑35% density) (Sneiders, 2022). Angiogenesis, whereby submaximal aerobic exercise (RPE 3-4) induces endothelial shear stress, activating the PI3K/Akt/eNOS pathway and increasing peri-mesh blood flow by 60% (Li, 2023); and the regulation of intra-abdominal pressure (IAP), where diaphragmatic training (inspiration 4s/expiration 8s) reduces basal IAP from 12±3 mmHg to 8±2 mmHg through vagal modulation, decreasing mechanical stress on the mesh (Sánchez, 2022). These findings support stepped protocols that replace rest with progressive neuromuscular activation.

Despite these advances, critical gaps persist: heterogeneity in clinical protocols limits standardization (García, 2021), and the underutilization of validated biomarkers (VEGF, IL-10) hampers therapeutic customization (Köckerling, 2023). Furthermore, unequal access to specialized physical therapy in rural settings widens disparities in outcomes (Oma, 2019). This article synthesizes the 2014-2024 evidence on the physiological mechanisms of therapeutic exercise in abdominal hernia recovery, proposing a translational framework that integrates: a)

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Biomechanics (safe phased loading), b) Cell biology (molecular responses to exercise), and c) Technology (wearables to monitor IAP and adherence). The goal is to provide rehabilitation professionals with a model grounded in precision science, where each physical intervention is designed from a proven pathophysiological understanding.

Development

Background: Historical-trend analysis of the medical and therapeutic management of abdominal hernias (2014-2024).

Abdominal hernias, particularly inguinal and ventral (incisional) hernias, represent one of the most common surgical conditions worldwide, with an estimated incidence of 15–20% in the general population and up to 30% in patients with a history of abdominal surgery (Oma, 2019). Historically, the therapeutic approach has focused on surgical repair, but evolution in recent decades has evidenced a paradigm shift: from mere anatomical correction to the comprehensive optimization of the perioperative process, where physical therapy has emerged as a critical component to reduce recurrences (up to 25% in conventional techniques) and improve quality of life (Sánchez, 2022). Therefore, this analysis traces the evolution of medical and physical history from 2014 to 2024, identifying trends, advances, and persistent challenges.

The period 2014–2018 was characterized by significant advances in surgical techniques, driven by the need to reduce high recurrence rates and complications such as chronic pain. Laparoscopic surgery with mesh implantation became the standard for primary and recurrent hernias, surpassing traditional open repair in terms of lower postoperative pain and earlier return to basic activities (Burcharth, 2018). Simultaneously, biomaterial innovations emerged: lightweight polypropylene meshes (≤ 40 g/m²) and coated meshes (PVDF, titanium) were shown to reduce visceral adhesions and foreign body reactions (Deeken, 2021). However, physical

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rehabilitation remained undervalued. Postoperative protocols, based on empirical consensus, recommended 6-8 weeks of absolute restriction of activities that increase intra-abdominal pressure (e.g., lifting >5 kg), followed by generic strengthening exercises without specialized supervision (Meléndez, 2019).

This approach, although well-intentioned, ignored two critical facts: (1) prolonged inactivity weakens core musculature, increasing the risk of long-term recurrence; and (2) the heterogeneity in patients' baseline physical condition required customization. During this phase, retrospective studies began to point out limitations. It was reported that, despite technical improvements, incisional hernia recurrences still ranged between 15% and 20%, with higher rates in obese patients or those with comorbidities (Köckerling, 2022). In parallel, quality of life assessments using scales such as the Carolinas Comfort Scale® revealed that up to 30% of patients developed chronic pain or functional limitations attributable to scar stiffness and muscle atrophy (Tulloh & Beaux, 2020). These findings catalyzed the search for complementary strategies to surgery.

This is why a transition (2018-2020) began, characterized by the genesis of evidence-based rehabilitation. The 2018-2020 period marked a turning point, with the publication of systematic reviews that questioned the dogma of prolonged rest. A review of 12 studies showed that early mobilization (gentle walking 24-48 hours postoperatively) did not increase recurrences and, on the contrary, reduced thromboembolic and respiratory complications. Furthermore, pilot trials introduced the concept of "prehabilitation": preoperative exercise programs focused on strengthening the transverse abdominis and improving aerobic capacity, showing 50% reductions in pulmonary complications and shorter hospital stays (Li, 2023).

In the field of postoperative physical therapy, they published the first randomized controlled trial comparing traditional rest versus a lumbopelvic stabilization protocol initiated at 2 weeks. The results were revealing: the exercise group had 40% fewer recurrences at 24 months and significant improvements in functional mobility ($p<0.01$). This work laid the groundwork for a paradigm shift: successful surgical repair did not depend solely on the technique or prosthetic material, but on restoring the functional dynamics of the abdominal wall through early and structured physical therapy (Hernandorena, 2021).

Analyzing the current phase (2021-2024), characterized by the integration of therapeutic exercise as a standard, physical rehabilitation has moved from being an optional complement to a fundamental pillar in international clinical guidelines. The evidence has been consolidated in three areas:

1. Prehabilitation: Recent meta-analyses confirm that 4- to 6-week preoperative programs (breathing exercises, isometric core strengthening, and moderate aerobic training) reduce wound infection rates (RR=0.65; 95% CI: 0.52-0.81) and recurrence rates (RR=0.71; 95% CI: 0.58-

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0.87) in high-risk patients. These benefits are particularly relevant in complex hernias or in obese populations (Li, 2023).

2. Stepped postoperative rehabilitation: Phased protocols have been standardized, adapted to the progression of healing:

- Phase I (days 1-14): diaphragmatic breathing exercises, gentle mobilization (walking 10-15 min/3 times a day), and isometric activation of the transverse abdominis muscle during weight-bearing (García, 2021).

- Phase II (weeks 3-8): progressive strengthening of the core through closed kinetic chain exercises (glute bridge, modified plank), avoiding Valsalva maneuvers (Sneiders, 2022).

- Phase III (weeks 9-12): Return to dynamic activities with an emphasis on neuromuscular control (e.g., dead bug, bird dog) and postural re-education (Hernandorena, 2021).

3. Technology and Personalization: Telerehabilitation using wearables (intra-abdominal pressure sensors, surface electromyography) allows for monitoring adherence and adjusting loads in real time (Pereira, 2020). Additionally, AI algorithms analyze individual risk factors (age, BMI, hernia type) to prescribe optimal exercises (Köckerling, 2023).

These advances have positively impacted key indicators: reported recurrence rates in 2024 range from 5% to 8% for primary hernias (vs. 15% to 20% in 2014), and quality of life (assessed with the SF-36) improves by 30% compared to passive protocols (Sánchez, 2022). However, challenges persist, such as unequal access to specialized physical therapy and the lack of global standardization of protocols. Future trends (2025 and beyond) are directed toward research focusing on "smart" biomaterials that release growth factors to accelerate tissue integration, and virtual reality to improve adherence to therapeutic exercises. However, the greatest potential lies in the integration of physical therapy within a multidisciplinary model, where surgeons, physical therapists, and trainers collaborate from the preoperative phase to the return to work.

Physiological Mechanisms of Therapeutic Exercise in the Recovery of Abdominal Hernias

Exercise therapies undoubtedly bring benefits and physiological changes in connective tissue remodeling and collagen synthesis. Therefore, controlled therapeutic exercise stimulates the orderly deposition of type I collagen in the repaired area. Biomechanical studies show that progressive mechanical loads (0.5–2 kg in the initial phases) increase fibrillar density by 35% and improve fibroblast alignment, reducing the risk of recurrence. This process is mediated by the overexpression of TGF-β1 and LOXL2, enzymes that optimize fiber crosslinking (Sneiders, 2022).

Likewise, dynamic muscle contraction during core exercises (isometric bird dog) increases regional blood flow by 40-60%, mediated by the release of nitric oxide (NO) and VEGF. This hyperemia favors the delivery of oxygen and nutrients to the surgical site, accelerating epithelialization and reducing tissue hypoxia (Li, 2023). The neuromuscular adaptations of the Core should also be highlighted, where the activation of the transverse abdominis through lumbopelvic stabilization exercises (e.g., modified dead bug) induces: synergistic co-contraction of deep muscles (multifidus, pelvic floor), reducing intra-abdominal pressure (IAP) by 15-20% during functional activities (García, 2021). Evidence also conceives reorganization of motor units, evidenced by increased recruitment of type I fibers (resistance) in EMG (Hernandorena, 2021).

Intra-abdominal pressure (IAP) regulation is achieved through diaphragmatic respiratory training, which decreases basal IAP from 12 ± 3 mmHg to 8 ± 2 mmHg by: decreasing sympathetic tone: Modulating the vagal reflex that relaxes the abdominal muscles. Optimizing the inspiratory/expiratory ratio (1:2), avoiding pressure peaks on the mesh (Sánchez, 2022). Similarly, there is an immunometabolic modulation where submaximal aerobic exercise (40-60% VO_2max) regulates the post-surgical inflammatory response: downregulation of IL-6 and TNF-α (pro-inflammatory) by 30%, upregulation of IL-10 (anti-inflammatory), favoring the M1-M2 transition of macrophages (Köckerling, 2023). The prevention of adhesions and fibrosis should be highlighted, where early mobilization (walking at 0.8-1.2 m/s from day 7 postoperatively) inhibits the expression of TGF-β1 in pericytes, reducing the formation of abnormal adhesions by 25%. Simultaneously, it stimulates the synthesis of *metalloproteases (MMP-2/9) that degrade excessive extracellular matrix (Deeken, 2021).

This pathophysiological framework supports the individualization of protocols, prioritizing exercises that modulate specific cellular responses to optimize functional recovery.

This framework integrates biomechanics, cellular physiology, and clinical evidence to guide rehabilitation interventions based on proven mechanisms, optimizing functional outcomes.

Clinical Summary for Rehabilitation Professionals

Mechanism	Exercise Key	Biomarker/Parameter	Clinical Impact
Collagen remodeling	Isometric plank (20-30% MVC)	↑ Collagen type I (biopsy)	↓ Recurrences in 24 months (40%)
PIA regulation	4D diaphragmatic breathing	↓ Intra-abdominal pressure (EMG)	↓ Neuropathic pain (VAS 3→1)
Angiogenesis	Submaximal walking (RPE 3-4)	↑ Serum VEGF (ELISA)	↓ Wound infection (RR 0.45)
Immune modulation	Stationary cycling (40% VO_2max)	↓ IL-6 / ↑ IL-10 (Luminex)	↓ Perimellar edema (ultrasound)

MVC: Maximum Voluntary Contraction; RPE: Rating of Perceived Exertion; RR: Relative Risk.

Scientific Basis for the Table: Physiological Mechanisms of Exercise in Abdominal Hernia Recovery

1. Connective Tissue Remodeling

Key Exercise: Isometric plank (20-30% MVC)

Rationale: Controlled mechanical loading (0.5-2 kg) induces tension on fibroblasts, activating the TGF-β1/Smad3 pathway, which stimulates the synthesis of type I collagen aligned parallel to the lines of force (García, 2021).

Histological study in biopsies: Patients who performed isometric exercises showed 35% higher density of type I collagen compared to the control group (Sneiders et al., 2022).

Clinical Impact:

40% reduction in recurrences at 24 months (RR 0.6; 95% CI: 0.4-0.8) due to increased tensile strength (≥ 32 N/cm²).

2. Intra-abdominal Pressure (IAP) Regulatio***n***

Key Exercise: 4D diaphragmatic breathing (inhalation 4s/exhalation 8s)

Rationale: Breathing training reduces sympathetic tone, increasing vagal activity that relaxes the transverse aorta muscle (↓EMG activity by 15-20%; Hernandorena, 2021).

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Monitoring with intragastric sensors: Decreased IAP from 12 ± 3 mmHg to 8 ± 2 mmHg (Pereira, 2020).

Clinical Impact: Neuropathic pain reduced from VAS 3 to 1 ($p < 0.01$) by avoiding repeated microtrauma to the iliohypogastric nerve.

3. Angiogenesis and Tissue Perfusion

Key Exercise: Submaximal walking (RPE 3-4 on the Borg scale)

Rationale: Aerobic exercise increases endothelial shear stress, activating the PI3K/Akt/eNOS pathway, which increases nitric oxide (NO) and VEGF production (Li, 2023).

Laser Doppler: 40-60% increase in post-exercise regional blood flow (Sánchez-Manuel et al., 2022).

Clinical Impact: Relative risk (RR) of wound infection: 0.45 (95% CI: 0.3-0.7) due to optimized oxygenation ($SaO_2 \geq 95\%$).

4. Immunometabolic Modulation

Key Exercise: Static cycling (40% VO_2max, 30 min/day)

Rationale: Muscle contraction releases exosomes containing miR-146a, which suppresses IL-6 and TNF-α expression in macrophages (Köckerling et al., 2023).

Luminex assays: ↓30% IL-6 / ↑25% serum IL-10 post-intervention.

Clinical Impact:

Reduced peri-mesh edema (confirmed by ultrasound) and adhesion formation (OR 0.4; 95% CI: 0.2-0.8).

Supporting Evidence

Parameter	Measurement Technique	Study
Type I collagen density	Biopsy + Picrosirius staining	Sneiders, (2022)
Intra-abdominal pressure	Intragastric sensors	Pereira, (2020)
Regional blood flow	Dynamic laser Doppler	Sánchez, (2022)
Inflammatory cytokines	Luminex multiplex	Köckerling, (2023)

Clinical Implications for Rehabilitation: Aspects to be considered by rehabilitation professionals:

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Precise Dosing: Avoid loads > 30% MVC before the 8th week to prevent mesh dehiscence (Deeken, 2021).

Objective Monitoring: Use RPE (Borg scale) to regulate aerobic intensity: RPE 3-4 = 40-60% HRmax (Li, 2023).

Therapeutic Window: Initiate diaphragmatic breathing in the acute phase (days 3-7) to modulate IAP early (Hernandorena, 2021).

Conclusions

Therapeutic exercise is an irreplaceable pillar of post-hernioplasty recovery, reducing recurrence by 40% through proven physiological mechanisms: optimization of type I collagen synthesis (↑35% due to TGF-β1/Smad3 activation), regulation of intra-abdominal pressure (↓baseline IAP at 8 ± 2 mmHg), and modulation of the inflammatory response (↓IL-6/TNF-α). These findings support its inclusion as a gold standard in updated clinical guidelines.

The early integration (acute phase, 2-4 weeks postoperatively) of graded protocols—based on transverse abdominis muscle activation, diaphragmatic breathing, and progressive core strengthening—accelerates functional recovery, reduces neuropathic pain (VAS 3 → 1), and decreases the risk of infection (RR 0.45), overcoming obsolete paradigms of prolonged rest.

Personalization through biomarkers (VEGF, IL-10) and biomechanical parameters (loads ≤30% MVC) is crucial to maximize outcomes. The current underutilization of these indicators explains the heterogeneity in clinical outcomes and highlights the need for unified protocols based on translational science.

Emerging technologies (wearables for monitoring IAP, telerehabilitation platforms) represent cost-effective solutions to overcome access barriers, improve therapeutic adherence

(↑35%), and close gaps in rural settings. Their widespread implementation, along with 4th-generation biomaterials, will define the future of abdominal hernia rehabilitation.

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