



Dynamic mechanical events after completion of minimally invasive hernia repair: an overlooked determinant of surgical success

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ABSTRACT

Technical success in minimally invasive hernia repair is traditionally assessed at the completion of surgery, assuming that the final intraoperative appearance accurately reflects the definitive state of the reconstruction. However, restoration of physiological loading immediately after surgery initiates a series of biomechanical events that may substantially alter repair behavior before biological tissue integration occurs.

This narrative review introduces the concept of the Dynamic Post-Closure Phase (DPCP), defined as the interval between completion of abdominal wall reconstruction and establishment of a new physiological mechanical equilibrium. During this phase, loss of pneumoperitoneum, collapse of the preperitoneal space, visceral redistribution, restoration of respiratory mechanics, transient pressure peaks, and early mobilization continuously modify the mechanical environment of the repair. We propose that these events should be regarded as a unified biomechanical process rather than isolated postoperative phenomena. Based on this framework, the mechanical consequences of the DPCP, including alterations in mesh configuration, redistribution of fascial tension, evolution of tissue apposition, and cumulative mechanical loading, are discussed. We further reinterpret contemporary surgical techniques and perioperative management strategies as complementary methods of preserving mechanical stability throughout this biomechanical transition.

Recognition of the Dynamic Post-Closure Phase provides a new conceptual framework linking operative reconstruction with postoperative mechanical loading. Viewing abdominal wall reconstruction as a dynamic rather than static process may improve interpretation of postoperative repair behavior, offer a unified explanation for previously disconnected clinical observations, and provide a foundation for future biomechanical research and optimization of abdominal wall reconstruction.

KEY WORDS: Abdominal wall reconstruction, biomechanics, postoperative loading, mechanical ventilation, dynamic post-closure phase, critical care.

INTRODUCTION

Minimally invasive hernia repair has evolved into a highly standardized procedure in which meticulous dissection, appropriate mesh positioning, and anatomical reconstruction are considered the principal determinants of technical success [1].

This concept, however, assumes that the mechanical conditions observed during the final intraoperative inspection remain unchanged after surgery. In reality, completion of the operation marks the beginning of a series of rapid biomechanical events that fundamentally alter the environment in which the reconstruction must function. Following completion of surgery, loss of pneumoperitoneum, restoration of physiological loading, respiratory activity, coughing, and mobilization progressively transform the mechanical environment of the repair. These events may alter mesh configuration, tissue apposition, and force distribution during the early postoperative period, when biological and inflammatory responses have already begun but substantial tissue integration has not yet developed, and mechanical factors remain particularly important for repair stability.

Although individual components of this process have been investigated previously, their temporal interplay during the immediate transition from operative to physiological mechanical conditions has received comparatively limited attention. The novelty of the proposed DPCP concept therefore lies in integrating these established biomechanical phenomena into a unified temporal framework rather than in the individual phenomena themselves. Consequently, this critical transition period remains largely overlooked in both surgical literature and perioperative management.

We propose that the interval between completion of reconstruction and establishment of physiological mechanical equilibrium constitutes a distinct biomechanical phase of abdominal wall repair. Recognition of this phase may provide a conceptual framework linking intraoperative surgical strategy with postoperative mechanical loading and may help explain why technically satisfactory repairs occasionally fail despite appropriate adherence to established surgical principles [2].

This review proposes a new conceptual framework for understanding abdominal wall reconstruction as a dynamic biomechanical process extending beyond completion of surgery.

LITERATURE SEARCH

This narrative review was based on a literature search of PubMed/MEDLINE conducted from database inception to August 2026. Search terms included combinations of “hernia repair”, “abdominal wall reconstruction”, “biomechanics”, “mesh”, “mesh deformation”, “intra-abdominal pressure”, “dynamic loading”, and “mechanical ventilation”. Relevant clinical, experimental, biomechanical and review articles addressing mechanical aspects of abdominal wall reconstruction were selected, and their reference lists were additionally screened for pertinent publications. No formal systematic-review methodology or risk-of-bias assessment was applied.

The Dynamic Post-Closure Phase: A Conceptual Framework

Completion of minimally invasive hernia repair is traditionally regarded as the endpoint of reconstruction. Once mesh placement, tissue closure, and hemostasis have been achieved, the procedure is considered technically complete. At this stage, however, the reconstructed abdominal wall has not yet reached mechanical equilibrium but instead enters a period of rapid biomechanical adaptation.

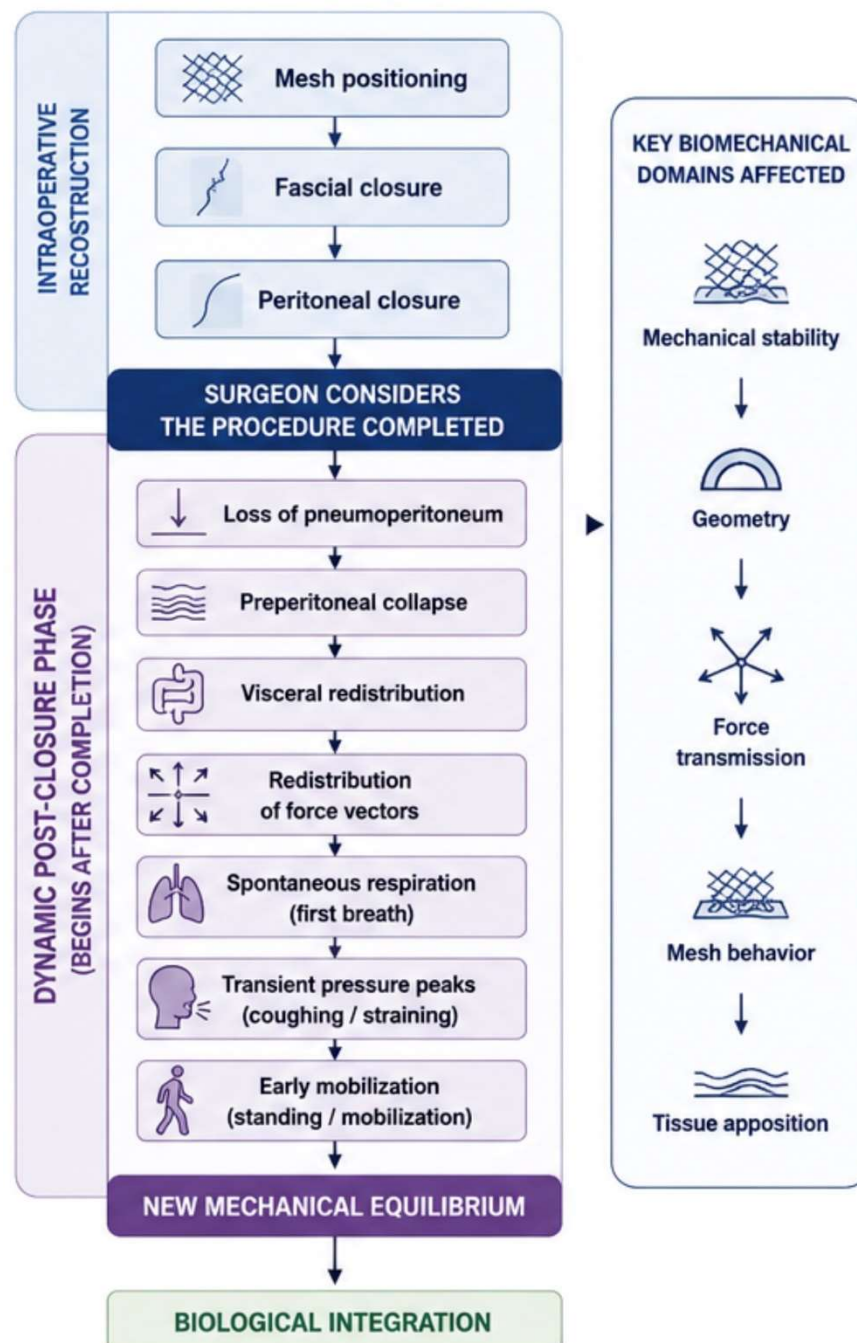


Figure 1. Proposed conceptual model of the Dynamic Post-Closure Phase: completion of surgery marks the beginning, not the end of abdominal wall reconstruction. Arrows indicate proposed conceptual relationships and do not imply established causality.

We propose that this interval constitutes a distinct biomechanical entity, termed the Dynamic Post-Closure Phase (DPCP). For the purposes of this framework, the DPCP begins with desufflation after completion of the load-bearing reconstruction, when the artificial operative mechanical environment is released, and extends until the repair reaches a relatively stable mechanical configuration under physiological loading. This represents a conceptual rather than a precisely measurable endpoint, and its duration may vary from the immediate postoperative period to several days depending on the type of repair and postoperative mechanical conditions. During this interval, mechanical factors may have a particularly important influence on repair behavior, while biological healing proceeds concurrently (Fig. 1) [3].

Table 1. Sequence of Dynamic Mechanical Events During the Dynamic Post-Closure Phase.

Stage	Primary biomechanical event	Principal mechanical consequence	Potential impact on reconstruction
<i>Core DPCP events</i>			
Loss of pneumoperitoneum	Normalization of intra-abdominal pressure	Change in abdominal geometry and force vectors	Initial alteration of mesh configuration and tissue apposition
Collapse of the preperitoneal space	Peritoneal settling onto the prosthesis	Mesh edge lifting, wrinkling, altered prosthesis–tissue contact	Reduced functional overlap, localized deformation
Redistribution of visceral loading	Return of abdominal organs to physiological position	Heterogeneous stress redistribution	Local stress concentrations and altered fascial tension
Restoration of spontaneous respiration	Cyclic respiratory loading	Repetitive tensile and compressive forces	Early cyclic loading before biological integration
Transient pressure peaks	Coughing, vomiting, straining	High-magnitude intermittent loading	Mesh displacement, suture overload, tissue deformation
Early mobilization	Upright posture and trunk muscle activation	Physiological multidirectional loading	Establishment of a new mechanical equilibrium
<i>Patient-specific modifiers</i>			
Positive-pressure ventilation*	Repetitive elevated airway pressures	Increased cyclic loading and elevated intra-abdominal pressure	Prolonged mechanical stress in critically ill patients
Obesity	Chronically elevated intra-abdominal pressure	Sustained mechanical loading	Increased fascial tension and mesh stress
Postoperative ileus	Persistent abdominal distension	Prolonged visceral loading	Delayed achievement of mechanical equilibrium

*Primarily applicable to critically ill patients. Potential impacts on reconstruction include proposed biomechanical mechanisms and should not necessarily be interpreted as established clinical consequences.

The Dynamic Post-Closure Phase is not a single event but a continuous mechanical transition in which each biomechanical change influences the next. Loss of pneumoperitoneum alters abdominal geometry; this modifies visceral loading and tissue apposition, which subsequently changes fascial tension, mesh configuration, and force transmission during respiration and movement [4]. The reconstructed abdominal wall therefore behaves as a dynamic mechanical system rather than a static structure created at the end of the operation.

This concept helps explain why technically satisfactory repairs occasionally develop unfavorable mesh configuration, altered tissue apposition, or excessive fascial loading despite apparently optimal intraoperative findings (Tab. 1). Because the reconstruction is assessed under artificial operative conditions, its subsequent behavior during the DPCP may differ substantially from its final intraoperative appearance [5]. Recognition of the DPCP provides a common biomechanical framework for interpreting a wide range of previously disconnected intraoperative and postoperative observations. Importantly, this phase is not intended to replace existing concepts of wound healing but to complement them by describing the purely mechanical transition that precedes biological integration.

Sequence of Dynamic Mechanical Events Following Minimally Invasive Hernia Repair

The Dynamic Post-Closure Phase consists of a continuous sequence of biomechanical events occurring immediately after completion of abdominal wall reconstruction. Although these events develop within a relatively short period, they progressively transform the mechanical environment of the repair. Rather than representing isolated phenomena, each event modifies the loading conditions for the subsequent stage, ultimately determining the mechanical equilibrium achieved by the reconstructed abdominal wall.

Loss of pneumoperitoneum

Loss of pneumoperitoneum represents the first major biomechanical transition of the DPCP [6]. As intra-abdominal pressure normalizes, abdominal geometry changes abruptly, initiating redistribution of visceral loading and force transmission across the reconstructed abdominal wall. Consequently, the final intraoperative assessment of mesh position and tissue apposition is performed under mechanical conditions that differ substantially from those encountered immediately after surgery. Importantly, these changes occur after completion of the technical procedure and therefore remain beyond direct surgical control [5].

Collapse of the preperitoneal space

Although collapse of the preperitoneal space appears to be a passive event, it may represent the most mechanically dynamic stage of minimally invasive preperitoneal repair. During this transition, variations in tissue collapse may theoretically alter mesh apposition and contribute to edge lifting, wrinkling, peritoneal interposition, or changes in prosthesis–tissue contact.

These effects represent plausible biomechanical mechanisms, although direct clinical evidence remains limited [7]. Paradoxically, these changes occur precisely when direct visualization has already been lost following peritoneal closure, leaving the surgeon unable to verify the final configuration of the repair. From a biomechanical perspective, controlled preperitoneal desufflation may temporarily restore visualization of this transition, potentially allowing otherwise unrecognized mesh configurations to be identified before restoration of physiological loading [8].

Redistribution of visceral loading

As intra-abdominal organs return to their physiological position, the reconstructed abdominal wall becomes exposed to its first physiological mechanical loading. Unlike the relatively uniform pressure generated by pneumoperitoneum, visceral loading is heterogeneous and continuously redistributed according to body position, organ mobility, and the geometry of the repair. Consequently, local stress concentrations may develop despite an apparently satisfactory intraoperative reconstruction [9]. Depending on the geometry of the repair, these forces may improve tissue apposition by increasing prosthesis–tissue contact or, conversely, promote localized deformation in mechanically unfavorable regions. Within the proposed DPCP framework, the configuration observed during the final laparoscopic inspection may therefore represent a temporary rather than definitive mechanical state of the reconstruction [10].

Restoration of physiological abdominal wall mechanics

Completion of anesthesia marks the transition from a relatively static intraoperative environment to continuous cyclic mechanical loading. Controlled mechanical ventilation is progressively replaced by spontaneous respiration, exposing the reconstructed abdominal wall to repetitive tensile and compressive forces before biological stabilization has occurred [11]. Although individually modest, respiratory forces represent the first continuous physiological stressor acting on the repair. In critically ill patients, prolonged mechanical ventilation and elevated airway pressures may amplify this repetitive loading and may potentially prolong or modify the DPCP [12]. Consequently, postoperative respiratory management should be regarded as an integral component of biomechanical reconstruction rather than merely supportive care.

Transient pressure peaks

Following extubation, the reconstructed abdominal wall becomes exposed to its first high-magnitude physiological loading. Coughing, vomiting, retching, straining, and patient agitation generate abrupt increases in intra-abdominal pressure that may exceed those encountered during quiet respiration by several-fold [5]. Importantly, these events occur before meaningful biological stabilization of the repair has developed.

Rather than causing immediate structural failure in isolation, transient pressure peaks should be viewed as cumulative mechanical stressors acting throughout the DPCP. Repeated episodes of high-magnitude loading may theoretically contribute to alterations in mesh position, localized tissue deformation, suture pull-through, and redistribution of mechanical stress across the reconstruction [13]. These should be

regarded as proposed biomechanical mechanisms rather than established clinical consequences of individual pressure peaks. Consequently, the mechanical behavior of the repair is determined not only by the magnitude of individual loading events but also by their cumulative effect before biological integration becomes established.

Early mobilization and the establishment of a new mechanical equilibrium

The final stage of the Dynamic Post-Closure Phase begins with restoration of upright posture and early mobilization. Standing, walking, changes in body position, and activation of the trunk musculature expose the reconstructed abdominal wall to physiological loading patterns fundamentally different from those encountered during surgery [14]. Importantly, the DPCP concept does not imply that routine early mobilization should be restricted and is fully compatible with established ERAS principles. Rather, early mobilization represents physiological loading to which the reconstruction must adapt, while the potential effects of excessive or pathological loading warrant further investigation.

By this stage, the repair has already undergone a sequence of biomechanical transitions involving changes in abdominal geometry, mesh configuration, visceral loading, respiratory mechanics, and transient pressure peaks. Collectively, these events progressively shape the mechanical state of the reconstruction. Eventually, the abdominal wall reaches a new physiological mechanical equilibrium in which the geometry of the repair, mesh position, fascial tension, visceral support, and external loading become relatively stable [15]. As mechanical conditions progressively stabilize, biological tissue integration, which begins concurrently during the early postoperative period, assumes an increasingly important role in long-term repair durability.

Mechanical Consequences of the Dynamic Post-Closure Phase

The biomechanical transitions described above are not merely transient phenomena but may permanently influence the final mechanical state of the reconstruction. During the Dynamic Post-Closure Phase, the repair remains highly susceptible to alterations in geometry, force transmission, and tissue interaction because biological integration has not yet occurred [16].

The relative contribution of individual DPCP components is expected to vary according to the type of repair. Preperitoneal space collapse and mesh settling are particularly relevant to TEP/TAPP repairs, whereas changes in fascial tension and abdominal wall geometry may be more prominent in ventral/incisional and retromuscular/eTEP reconstruction. In IPOM repair, intraperitoneal mesh position and fixation create different mechanical conditions. Thus, DPCP should be regarded as a common conceptual framework whose individual components and their relative importance are procedure-dependent.

Unlike late postoperative failure, which is predominantly determined by tissue biology and long-term remodeling, the consequences of the Dynamic Post-Closure Phase are primarily mechanical [17]. They arise from changes in mesh configuration, fascial tension, tissue apposition, and cumulative loading rather than deterioration of tissue quality itself.

For conceptual clarity, these mechanical consequences can be grouped into four principal domains: alterations in mesh configuration, redistribution of fascial tension, evolution of tissue apposition, and repetitive mechanical loading.

Although many of the proposed DPCP mechanisms relate to mesh-reinforced repair, the framework may also apply to primary suture repairs. In mesh-reinforced reconstruction, mechanical loads can be distributed across a broader mesh–tissue interface, whereas in primary suture repair loading is concentrated at the suture–fascia interface. Consequently, cyclic loading and transient pressure peaks may theoretically result in different mechanical responses, including localized tissue deformation, suture pull-through or progressive loss of approximation in suture-based repairs. These mechanisms remain hypothesis-generating and should not be interpreted as established explanations for differences in clinical recurrence.

Alterations in mesh configuration

Mesh configuration established during surgery should not be regarded as definitive. Throughout the DPCP, the prosthesis continues to adapt to changing mechanical conditions before biological fixation develops. Consequently, even correctly positioned mesh may undergo edge lifting, folding, wrinkling, localized deformation, or transient displacement, reducing functional overlap despite apparently satisfactory intraoperative placement [18].

Because these adaptations occur during the biomechanical transition rather than during implantation itself, final mesh behavior cannot always be predicted from its appearance during the last intraoperative inspection. Recent intraoperative observations demonstrate that many of these configurations become apparent only during controlled collapse of the preperitoneal space [19]. Accordingly, mesh implantation should be regarded as a process of dynamic stabilization rather than a static act of prosthesis placement.

Redistribution of fascial tension

Mechanical equilibrium of the abdominal wall depends not only on the magnitude of applied forces but also on their spatial distribution. Consequently, even subtle alterations in force vectors during the DPCP may substantially influence the mechanical stability of the reconstruction [20].

As physiological loading is restored, redistribution of fascial tension may generate localized stress concentrations despite technically satisfactory defect closure. The final mechanical performance of the repair therefore depends not only on the quality of fascial approximation but also on the geometry through which forces are transmitted across the reconstructed abdominal wall.

This principle is particularly relevant in anatomically challenging defects, such as lateral incisional hernias, where the absence of a central anchoring structure creates inherently unfavorable force vectors [21]. Optimization of defect geometry before definitive closure may reduce peak tension, redistribute mechanical stress more uniformly, and improve stability throughout the DPCP.

Accordingly, successful abdominal wall reconstruction should be understood not simply as defect closure but as the creation of a mechanically favorable force-transmission system capable of maintaining stability under physiological loading.

Evolution of tissue apposition

Mechanical stability depends not only on the position of sutures or prosthetic material but also on the quality of contact established between adjacent biological surfaces. Immediately after reconstruction, tissue apposition remains a dynamic rather than static property of the repair [22]. Before biological adhesion develops, the quality of contact between fascial surfaces, prosthetic material, and surrounding tissues is determined almost exclusively by mechanical conditions. Consequently, transient tissue interposition, incomplete surface contact, or localized separation may influence the subsequent architecture of the reconstruction despite technically satisfactory intraoperative repair.

Because biological integration has not yet occurred, maintenance of stable tissue apposition relies entirely on mechanical factors. Even short-lived disturbances during this period may influence subsequent tissue incorporation and alter the distribution of mechanical loads across the repair [23].

Accordingly, tissue apposition should not be regarded as a single intraoperative event but as a dynamic process that evolves throughout the DPCP.

Cyclic mechanical loading

Following completion of surgery, the reconstructed abdominal wall is immediately exposed to repetitive mechanical loading generated by respiration, coughing, changes in posture, and early mobilization [24]. Unlike isolated loading events, these cyclic forces repeatedly stress the same tissue–suture and tissue–mesh interfaces before meaningful biological reinforcement has occurred.

Repetitive loading may contribute to gradual microdisplacement, progressive stress redistribution, accumulation of mechanical fatigue, and subtle alterations in the architecture of the reconstruction. Consequently, the mechanical behavior of the repair is influenced not only by the magnitude of individual loading events but also by their cumulative effect throughout the DPCP [25].

The importance of cumulative loading becomes even more pronounced in critically ill patients, in whom prolonged mechanical ventilation, elevated intra-abdominal pressure, repeated recruitment maneuvers, persistent coughing, or abdominal distension substantially increase both the magnitude and frequency of mechanical stress. Under these circumstances, the DPCP may be prolonged and mechanically intensified, increasing the vulnerability of the reconstruction.

Accordingly, postoperative mechanical loading should be regarded as a modifiable determinant of reconstruction stability rather than an unavoidable consequence of surgery.

Current Surgical Strategies as Methods of Mechanical Control

Current innovations in abdominal wall reconstruction are commonly presented as solutions to individual technical challenges, including fascial approximation, mesh positioning, fixation, and postoperative support [26]. From a biomechanical perspective, however, these seemingly independent interventions share a common objective: preserving mechanical stability throughout the Dynamic Post-Closure Phase.

Rather than representing isolated technical refinements, these approaches can be understood as complementary strategies acting at different stages of the same biomechanical continuum. Some modify the geometry of the reconstruction, others influence force transmission, mesh behavior, or postoperative loading, yet all ultimately seek to preserve mechanical stability until biological integration becomes established [27]. Viewed collectively, these techniques suggest that surgeons have long been attempting to control the Dynamic Post-Closure Phase without explicitly recognizing it as a distinct biomechanical entity (Fig. 2).

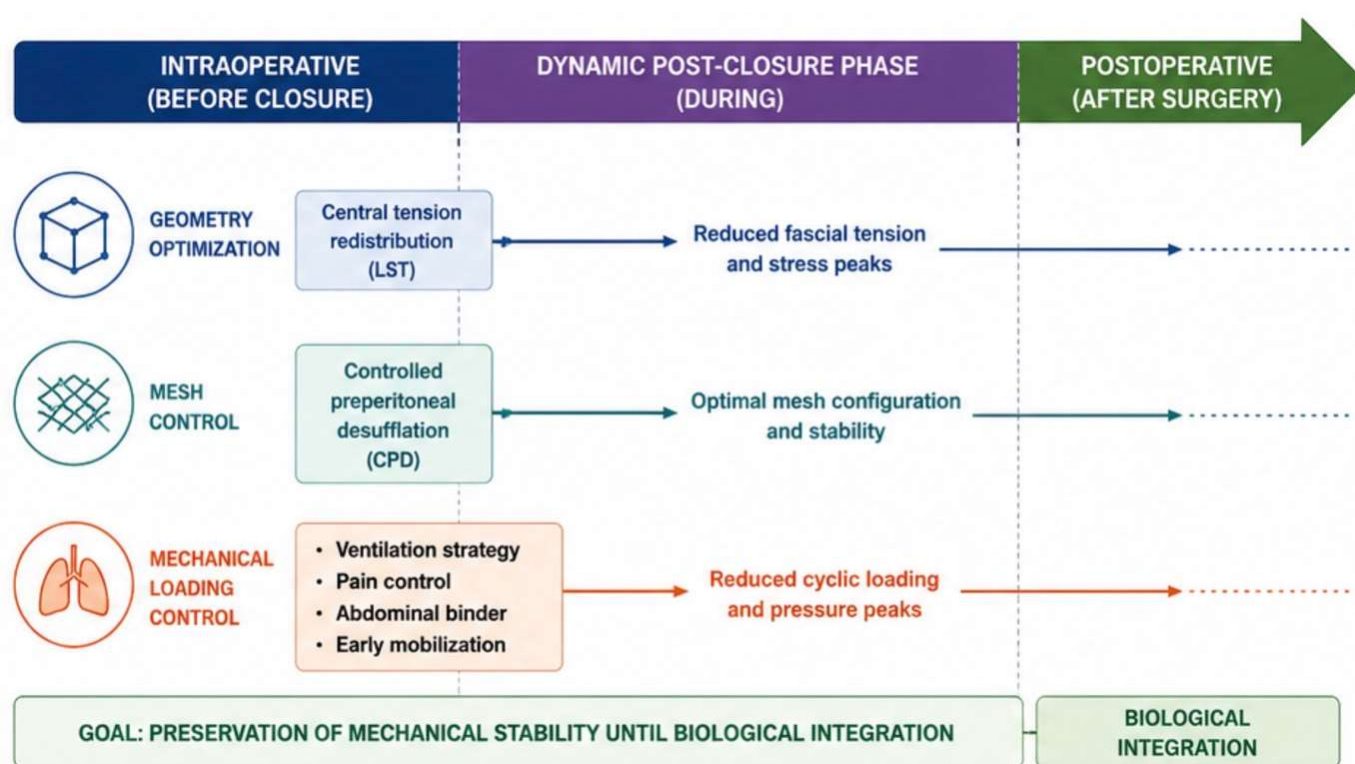


Figure 2. Proposed conceptual model illustrating how current surgical strategies may target different stages of the Dynamic Post-Closure Phase. Arrows indicate proposed conceptual relationships and do not imply established causality.

Geometry optimization before definitive closure

The earliest opportunity to influence postoperative mechanics occurs before completion of fascial closure. From a biomechanical perspective, defect geometry may influence both the magnitude and direction of forces transmitted across the reconstructed abdominal wall [28]. Consequently, optimization of defect geometry modifies the mechanical environment of the repair before physiological loading is restored.

Importantly, geometry optimization does not increase tissue strength; instead, it reduces the mechanical demands placed upon the reconstruction [29]. This distinction may explain why techniques based on progressive central force redistribution facilitate closure even in anatomically unfavorable defects without requiring more extensive tissue dissection or excessive suture tension.

Accordingly, successful fascial closure should be regarded not merely as approximation of tissue edges but as establishment of a mechanically favorable geometry capable of maintaining stability throughout the DPCP.

Control of mesh behavior during mechanical transition

The success of prosthetic repair depends not only on appropriate mesh selection but also on how the prosthesis behaves during the biomechanical transition from operative to physiological conditions. The DPCP represents the only interval during which substantial changes in mesh configuration may still occur before tissue incorporation develops [30]. Consequently, the final configuration of the prosthesis cannot always be predicted from its appearance during the last intraoperative inspection. The mechanical response of the prosthesis during this transition may also depend on mesh-specific properties, including anisotropy, stiffness and compliance. Differences in these characteristics may influence mesh deformation and load distribution under physiological loading, while the evolving mesh–tissue interface progressively modifies force transmission as tissue integration develops. These factors may therefore act as important modifiers of mesh behavior during the DPCP.

The feasibility of directly observing this otherwise hidden transition demonstrates that biomechanical adaptation during the DPCP is not merely theoretical but can be visualized intraoperatively [31]. Strategies allowing observation or control of this transition provide an opportunity to identify and correct unfavorable mechanical configurations before the reconstruction becomes mechanically stabilized. Rather than representing an additional technical maneuver, these approaches restore surgical control over a biomechanical process that would otherwise remain invisible.

Modulation of postoperative loading

Mechanical control does not end when surgery is completed. Following reconstruction, external forces become the principal determinants of repair behavior. Pain management, optimization of respiratory mechanics, early mobilization protocols, avoidance of excessive intra-abdominal pressure, and appropriate external abdominal support all influence the magnitude and frequency of mechanical loading throughout the DPCP [32].

Although these interventions are traditionally regarded as components of postoperative care, they may also modify the mechanical environment of the reconstruction. In particular, abdominal binders have demonstrated potential clinical benefits regarding postoperative pain, mobility and selected wound-related outcomes [33–36], whereas their direct effect on mesh geometry, reconstruction stability or recurrence

remains unproven. Within the DPCP framework, such a mechanical effect should therefore be regarded as a proposed mechanism rather than an established clinical benefit.

Critical care as an extension of abdominal wall reconstruction

The importance of mechanical control becomes particularly evident in critically ill patients. Mechanical ventilation, elevated positive airway pressures, repeated recruitment maneuvers, persistent coughing, abdominal distension, agitation, and delayed mobilization may modify and potentially prolong the mechanical transition represented by the DPCP [37]. Under these circumstances, the reconstructed abdominal wall remains exposed to repetitive loading long before meaningful biological strengthening has occurred [38]. Consequently, the success of abdominal wall reconstruction in critically ill patients depends not only on operative technique but also on how postoperative mechanical forces are managed. Rather than representing merely supportive treatment, intensive care should be regarded as a continuation of abdominal wall reconstruction, where optimization of the mechanical environment becomes an integral component of surgical success.

Toward Dynamic Surgery

Collectively, these observations suggest that abdominal wall reconstruction should be understood as a process of continuous mechanical control rather than a sequence of isolated technical steps. From a biomechanical perspective, the traditional distinction between operative technique and postoperative care becomes increasingly artificial [36]. Surgery establishes the initial mechanical state of the reconstruction, whereas perioperative management determines how that reconstruction responds to physiological loading until biological integration becomes established [39].

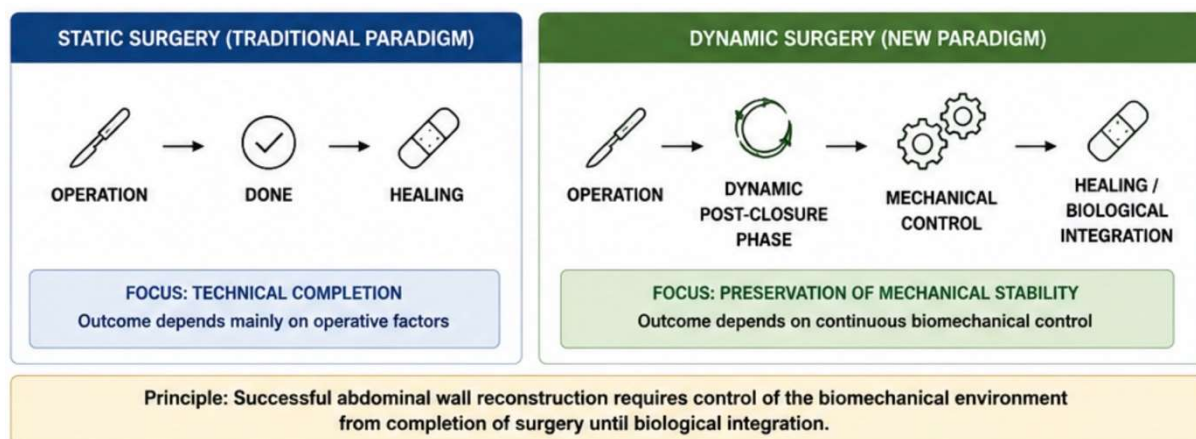


Figure 3. From static repair to dynamic surgery: a new conceptual framework for abdominal wall reconstruction.

Arrows indicate proposed conceptual relationships and do not imply established causality.

This perspective shifts the definition of successful abdominal wall reconstruction from technical completion of the operation to preservation of mechanical stability throughout the Dynamic Post-Closure Phase (Fig. 3). In this sense, dynamic surgery is defined not by additional operative maneuvers but by continuous control of the biomechanical environment in which reconstruction evolves.

Future Directions: From Static Repair to Dynamic Surgery

Recognition of the Dynamic Post-Closure Phase opens new perspectives for both research and clinical practice. Rather than focusing exclusively on individual technical aspects of abdominal wall reconstruction, future investigations should evaluate the entire biomechanical continuum extending from completion of surgery to biological tissue integration. Current assessment of surgical quality remains largely procedure oriented [40]. Parameters such as defect closure, mesh overlap, fixation strategy, operative time, and postoperative complications provide only a static assessment of a reconstruction that subsequently undergoes continuous biomechanical adaptation [41].

Future studies should therefore focus on objective characterization of the Dynamic Post-Closure Phase [42]. Quantitative assessment of mesh behavior, force transmission, abdominal wall mechanics, and computational biomechanical modelling may improve understanding of why technically satisfactory reconstructions occasionally fail despite adherence to current surgical principles [43–44]. Recent studies increasingly support a dynamic view of abdominal-wall reconstruction. Contemporary EHS guidelines emphasize the importance of repair geometry and mesh reinforcement, while biomechanical studies by Kallinowski and colleagues have highlighted the relevance of pressure-related and cyclic loading [45–47]. More recent work on biomechanically calculated abdominal-wall repair and clinically applied mesh biomechanics further supports the importance of load distribution and tissue–prosthesis interaction. Importantly, dynamic MRI has demonstrated measurable changes in abdominal-wall mechanics during breathing, coughing and Valsalva before and after ventral hernia repair [48, 49]. These observations provide an important experimental and clinical background for future evaluation of the proposed DPCP framework.

Importantly, the implications of this concept extend beyond abdominal wall surgery. Similar transitions between operative reconstruction and biological stabilization occur wherever tissues or implanted materials are exposed to changing mechanical environments. The DPCP may therefore represent a broader biomechanical principle applicable to reconstructive surgery as a whole.

CONCLUSIONS

A technically satisfactory reconstruction performed under artificial operative conditions does not necessarily remain mechanically optimal once physiological loading is restored. Completion of surgery should therefore be regarded not as the end of abdominal wall reconstruction, but as the beginning of a distinct biomechanical transition.

We propose the Dynamic Post-Closure Phase (DPCP) as a conceptual framework integrating the sequence of mechanical events occurring immediately after minimally invasive hernia repair. This perspective helps explain why technically appropriate repairs may evolve differently after surgery and suggests that successful reconstruction depends not only on operative technique but also on preservation of mechanical stability throughout the transition from operative to physiological conditions.

The DPCP should therefore be regarded as a hypothesis-generating conceptual model that requires prospective validation. Future studies using dynamic MRI or ultrasound, CT with Valsalva, intra-abdominal pressure monitoring, imaging of mesh displacement or deformation, and computational modelling may help objectively characterize this proposed mechanical transition and determine its clinical relevance.

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REFERENCES

- [1] Bittner R, Montgomery MA, Arregui E, Bansal V, Bingener J, Bisgaard T, et al. International Endohernia Society. Update of guidelines on laparoscopic (TAPP) and endoscopic (TEP) treatment of inguinal hernia (International Endohernia Society). *Surg Endosc*. 2015; 29(2): 289-321.
doi: <https://doi.org/10.1007/s00464-014-3917-8>
- [2] HerniaSurge Group. International guidelines for groin hernia management. *Hernia*. 2018; 22(1): 1-165.
doi: <https://doi.org/10.1007/s10029-017-1668-x>
- [3] Klinge U, Klosterhalfen B. Modified classification of surgical meshes for hernia repair based on the analyses of 1,000 explanted meshes. *Hernia*. 2012; 16(3): 251-258.
doi: <https://doi.org/10.1007/s10029-012-0913-6>
- [4] Deeken CR, Lake SP. Mechanical properties of the abdominal wall and biomaterials utilized for hernia repair. *J Mech Behav Biomed Mater*. 2017; 74: 411-427.
doi: <https://doi.org/10.1016/j.jmbbm.2017.05.008>
- [5] Cobb WS, Burns JM, Kercher KW, Matthews BD, James Norton H, Todd Heniford B. Normal intraabdominal pressure in healthy adults. *J Surg Res*. 2005; 129(2): 231-235.
doi: <https://doi.org/10.1016/j.jss.2005.06.015>
- [6] Rosin D, Kuriansky J, Rosenthal RJ, Brascesco O, Ayalon A. Laparoscopic transabdominal suspension sutures. *Surg Endosc*. 2001; 15(7): 761-763.
doi: <https://doi.org/10.1007/s004640080101>
- [7] Belyansky I, Tsriline VB, Klima DA, Walters AL, Lincourt AE, Heniford TB. Prospective, comparative study of postoperative quality of life in TEP, TAPP, and modified Lichtenstein repairs. *Ann Surg*. 2011; 254(5): 709-714; discussion 714-715.
doi: <https://doi.org/10.1097/SLA.0b013e3182359d07>
- [8] Köckerling F, Bittner R, Jacob DA, Seidelmann L, Keller T, Adolf D, et al. TEP versus TAPP: comparison of the perioperative outcome in 17,587 patients with a primary unilateral inguinal hernia. *Surg Endosc*. 2015; 29(12): 3750-3760.
doi: <https://doi.org/10.1007/s00464-015-4150-9>
- [9] Harlaar JJ, Deerenberg EB, Dwarkasing RS, Kamperman AM, Kleinrensink GJ, Jeekel J, et al. Development of incisional herniation after midline laparotomy. *BJS Open*. 2017; 1(1): 18-23.
doi: <https://doi.org/10.1002/bjs5.3>

- [10] Nova A, Rezoagli E, Mietto C, Talmor D, Britto Passos Amato M, Cereda M, et al. Obesity: biomechanical implications for mechanical ventilation. *Crit Care*. 2026; 30(1): 375.
doi: <https://doi.org/10.1186/s13054-026-06181-9>
- [11] Malbrain ML, Cheatham ML, Kirkpatrick A, Sugrue M, Parr M, De Waele J, et al. Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. I. Definitions. *Intensive Care Med*. 2006; 32(11): 1722-1732.
doi: <https://doi.org/10.1007/s00134-006-0349-5>
- [12] Kirkpatrick AW, Roberts DJ, De Waele J, Jaeschke R, Malbrain MLNG, Dr Keulenaer B, et al. Pediatric Guidelines Sub-Committee for the World Society of the Abdominal Compartment Syndrome. Intra-abdominal hypertension and the abdominal compartment syndrome: updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome. *Intensive Care Med*. 2013; 39(7): 1190-1206.
doi: <https://doi.org/10.1007/s00134-013-2906-z>
- [13] Malbrain ML, De Laet I, Cheatham M. Consensus conference definitions and recommendations on intra-abdominal hypertension (iah) and the abdominal compartment syndrome (acs) - the long road to the final publications, how did we get there? *Acta Clin Belg*. 2007; 62 Suppl 1: 44-59.
- [14] Gutama B, Okundia S, Abbas H, Kalogeromitros M, Prabhu VA, Shah BJ, et al. Abdominal Wall Reconstruction: A Literature Review. *Ann Plast Surg*. 2026; 97(3S): S260-S271.
doi: <https://doi.org/10.1097/SAP.0000000000004788>
- [15] Grant MC, Engelman DT. Enhanced recovery after surgery: overarching themes of the ERAS® Society Guidelines & Consensus Statements for Adult Specialty Surgery. *Perioper Med (Lond)*. 2025; 14(1): 120.
doi: <https://doi.org/10.1186/s13741-025-00590-0>
- [16] Govillot L, Bellemin A, Baratte C, Giovinazzo D, Moszkowicz D. Incisional hernia repair with mesh: How I choose it? *J Visc Surg*. 2026; S1878-7886(26)00105-0.
doi: <https://doi.org/10.1016/j.jviscsurg.2026.06.007>
- [17] Bellón JM, García-Carranza A, García-Honduvilla N, Carrera-San Martín A, Buján J. Tissue integration and biomechanical behaviour of contaminated experimental polypropylene and expanded polytetrafluoroethylene implants. *Br J Surg*. 2004; 91(4): 489-494.
doi: <https://doi.org/10.1002/bjs.4451>
- [18] Lowham AS, Filipi CJ, Fitzgibbons RJ Jr, Stoppa R, Wantz GE, Felix EL, et al. Mechanisms of hernia recurrence after preperitoneal mesh repair. Traditional and laparoscopic. *Ann Surg*. 1997; 225(4): 422-431.
doi: <https://doi.org/10.1097/0000658-199704000-00012>
- [19] Sato M, Nozawa M, Watanabe T, Onoda T, Matsuyama A, Shiiya N, et al. Insufficiency of prosthetic posterolateral overlap related to recurrence after laparoscopic transabdominal preperitoneal inguinal hernioplasty, as assessed by video review. *BMC Surg*. 2020; 20(1): 27
doi: <https://doi.org/10.1186/s12893-020-0690-6>
- [20] Förstemann T, Trzewik J, Holste J, Batke B, Konerding MA, Wolloscheck T, et al. Forces and deformations of the abdominal wall—a mechanical and geometrical approach to the linea alba. *J Biomech*. 2011; 44(4): 600-606.
doi: <https://doi.org/10.1016/j.jbiomech.2010.11.021>
- [21] Mitura K, Kisieliwski K, Romanczuk M, Bernard M, Sawicka M, Kacprzak L, et al. Laparoscopic Suitcase Technique for lateral incisional hernias enables fully laparoscopic fascial closure: a retrospective comparative study. *BMC Surg*. 2026; 26(1): 346.
doi: <https://doi.org/10.1186/s12893-026-03731-4>
- [22] Bellón JM, Contreras LA, Buján J, Palomares D, Carrera-San Martín A. Tissue response to polypropylene meshes used in the repair of abdominal wall defects. *Biomaterials*. 1998; 19(7-9): 669-675.
doi: [https://doi.org/10.1016/s0142-9612\(97\)00162-2](https://doi.org/10.1016/s0142-9612(97)00162-2)
- [23] Endo M, Feola A, Sindhwani N, Manodoro S, Vlacil J, Engels AC, et al. Mesh contraction: in vivo documentation of changes in apparent surface area utilizing meshes visible on magnetic resonance imaging in the rabbit abdominal wall model. *Int Urogynecol J*. 2014; 25(6): 737-743.
doi: <https://doi.org/10.1007/s00192-013-2293-6>
- [24] Tomaszewska A, Lubowiecka I, Szymczak C. Mechanics of mesh implanted into abdominal wall under repetitive load. Experimental and numerical study. *J Biomed Mater Res B Appl Biomater*. 2019; 107(5): 1400-1409.
doi: <https://doi.org/10.1002/jbm.b.34232>

- [25] Kallinowski F, Baumann E, Harder F, Siassi M, Mahn A, Vollmer M, et al. Dynamic intermittent strain can rapidly impair ventral hernia repair. *J Biomech.* 2015; 48(15): 4026-4036.
doi: <https://doi.org/10.1016/j.jbiomech.2015.09.045>
- [26] Boukovalas S, Sisk G, Selber JC. Abdominal Wall Reconstruction: An Integrated Approach. *Semin Plast Surg.* 2018; 32(3): 107-119.
doi: <https://doi.org/10.1055/s-0038-1667062>
- [27] Rangwani SM, Kraft CT, Schneeberger SJ, Khansa I, Janis JE. Strategies for Mesh Fixation in Abdominal Wall Reconstruction: Concepts and Techniques. *Plast Reconstr Surg.* 2021; 147(2): 484-491.
doi: <https://doi.org/10.1097/PRS.0000000000007584>
- [28] Carnelli D, Gastaldi D, Sassi V, Contro R, Ortiz C, Vena P. A finite element model for direction-dependent mechanical response to nanoindentation of cortical bone allowing for anisotropic post-yield behavior of the tissue. *J Biomech Eng.* 2010; 132(8): 081008.
doi: <https://doi.org/10.1115/1.4001358>
- [29] Pereira X, De Oliveira P, Tagerman D, Romero-Velez G, Liu R, Malcher F. How I do it: using physics and progressive defect tensioning to close large hernia defects during MIS ventral hernia repair. *Hernia.* 2024; 29(1): 55.
doi: <https://doi.org/10.1007/s10029-024-03230-6>
- [30] Choy C, Shapiro K, Patel S, Graham A, Ferzli G. Investigating a possible cause of mesh migration during totally extraperitoneal (TEP) repair. *Surg Endosc.* 2004; 18(3): 523-525.
doi: <https://doi.org/10.1007/s00464-003-8183-0>
- [31] Soeta N, Saito T, Ito F, Gotoh M. Preperitoneal Suction Technique to Secure the Proper Mesh Position During Laparoscopic Herniorrhaphy. *Surg Laparosc Endosc Percutan Tech.* 2016; 26(6): e167-e170.
doi: <https://doi.org/10.1097/SLE.0000000000000338>
- [32] Michot N, Ortega-Deballon P, Karam E, Pabst-Giger U, Ouaisi M. Is There a Clinical Benefit of Abdominal Binders After Abdominal Surgery: A Systematic Literature Review. *J Abdom Wall Surg.* 2024; 3: 13506.
doi: <https://doi.org/10.3389/jaws.2024.13506>
- [33] Mitura K, Pajer M, Kacprzak L, Mitura B, Antosik K, Leszczyński PK, et al. The true purpose of the use of abdominal binders after incisional hernia repair: to reduce the stress forces along the suture line, to increase compression around the mesh, or to maintain the trunk circumference - a comprehensive literature review. *Pol Przegl Chir.* 2025; 97(3): 79-88.
doi: <https://doi.org/10.5604/01.3001.0055.0383>
- [34] Paasch C, Santo G, Aljedani N, Ortiz P, Bruckert L, Hünerbein M, et al. The Effect of an Abdominal Binder on Postoperative Pain After Laparoscopic Incisional Hernia Repair (ABIHR-I). *Dtsch Arztebl Int.* 2021; 118: 607-613.
doi: <https://doi.org/10.3238/arztebl.m2021.0250>
- [35] Ortiz PR, Lorenz E, Meyer F, Croner R, Lünse S, Hunger R, et al. The effect of an abdominal binder on postoperative outcome after open incisional hernia repair in sublay technique (ABIHR-II). *Hernia.* 2023; 27: 1263-1271.
doi: <https://doi.org/10.1007/s10029-023-02838-4>
- [36] Graziani AGE, Prajante Bertolino E, Godoi A, Florêncio de Mesquita C, Quisiguina SIC, et al. Effect of an abdominal binder on postoperative outcomes after ventral hernia repair: a systematic review and meta-analysis of randomized controlled trials. *Hernia.* 2025; 29(1): 20.
doi: <https://doi.org/10.1007/s10029-024-03193-8>
- [37] Regli A, Pelosi P, Malbrain MLNG. Ventilation in patients with intra-abdominal hypertension: what every critical care physician needs to know. *Ann Intensive Care.* 2019; 9(1): 52.
doi: <https://doi.org/10.1186/s13613-019-0522-y>
- [38] Petro CC, Raigani S, Fayeziadeh M, Rowbottom JR, Klick JC, Prabhu AS, et al. Permissible Intraabdominal Hypertension following Complex Abdominal Wall Reconstruction. *Plast Reconstr Surg.* 2015; 136(4): 868-881.
doi: <https://doi.org/10.1097/PRS.0000000000001621>
- [39] Parker SG, Halligan S, Blackburn S, Plumb AAO, Archer L, Mallett S, et al. What Exactly is Meant by "Loss of Domain" for Ventral Hernia? Systematic Review of Definitions. *World J Surg.* 2019; 43(2): 396-404.
doi: <https://doi.org/10.1007/s00268-018-4783-7>

- [40] Slater NJ, Montgomery A, Berrevoet F, Carbonell AM, Chang A, Franklin M, et al. Criteria for definition of a complex abdominal wall hernia. *Hernia*. 2014; 18(1): 7-17.
doi: <https://doi.org/10.1007/s10029-013-1168-6>
- [41] Muysoms FE, Antoniou SA, Bury K, Campanelli G, Conze J, Cuccurullo D, et al. European Hernia Society. European Hernia Society guidelines on the closure of abdominal wall incisions. *Hernia*. 2015; 19(1): 1-24.
doi: <https://doi.org/10.1007/s10029-014-1342-5>
- [42] Perez MM, Dumanian GA, Hackenberger PN, Ross D, Stulberg J, Shapiro M. A Narrative Review of Mesh Suture in Abdominal Wall Reconstruction: Biomechanics, Early Outcomes, and Proposed Clinical Algorithm. *J Abdom Wall Surg*. 2025; 4: 15452.
doi: <https://doi.org/10.3389/jaws.2025.15452>
- [43] Karrech A, Ahmad H, Hamdorf JM. Biomechanical stability of hernia-damaged abdominal walls. *Sci Rep*. 2023; 13(1): 4936.
doi: <https://doi.org/10.1038/s41598-023-31674-w>
- [44] Ellis R, Miller BT. Mesh Selection in Abdominal Wall Reconstruction: An Update on Biomaterials. *Surg Clin North Am*. 2023; 103(5): 1019-1028.
doi: <https://doi.org/10.1016/j.suc.2023.04.010>
- [45] Sanders DL, Pawlak MM, Simons MP, Aufenacker T, Balla A, Berger C, et al. Midline incisional hernia guidelines: the European Hernia Society. *Br J Surg*. 2023; 110: 1732–1768.
doi: <https://doi.org/10.1093/bjs/znad284>
- [46] Kallinowski F, Ludwig Y, Löffler T, Vollmer M, Lösel PD, Voß S, et al. Biomechanics applied to incisional hernia repair – considering the critical and the gained resistance towards impacts related to pressure. *Clin Biomech*. 2021; 82: 105253.
doi: <https://doi.org/10.1016/j.clinbiomech.2020.105253>
- [47] Nessel R, Löffler T, Rinn J, Lösel P, Voss S, Heuveline V, et al. Primary and recurrent repair of incisional hernia based on biomechanical considerations to avoid mesh-related complications. *Front Surg*. 2021; 8: 764470.
doi: <https://doi.org/10.3389/fsurg.2021.764470>
- [48] Jinka SKA, Janis JE. Clinically Applied Biomechanics of Mesh-reinforced Ventral Hernia Repair: A Practical Review. *Plast Reconstr Surg Glob Open*. 2024; 12(11): e6294.
doi: <https://doi.org/10.1097/GOX.00000000000006294>
- [49] Joppin V, Bendahan D, Ahmadi AAE, Masson C, Bege T. Biomechanics of the abdominal wall before and after ventral hernia repair using dynamic MRI. *Hernia*. 2025; 29(1): 185.
doi: <https://doi.org/10.1007/s10029-025-03337-4>