

## Commentary

# Why Might Evolution Favor Geometric Locking Rather Than Continuous Suspension in the Human Pelvic Floor? A First-Principles Hypothesis Framed by the Principle of Least Action

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For more than five decades, influential models of female pelvic floor support have emphasized suspensory and muscular support: pelvic organs are stabilized by connective-tissue attachments and pelvic floor muscles that oppose gravity and intra-abdominal pressure. These models have been foundational, yet recurrent prolapse, incomplete functional recovery after anatomical correction, and implant-related complications suggest that long-term pelvic floor stability may not be explained by suspensory load bearing alone. We propose a complementary, testable hypothesis: the human pelvic floor may achieve part of its long-term stability through dynamic geometric locking. In this view, the pelvic organs, levator plate, perineal body, vaginal walls, and apical structures form a coupled mechanical system in which controlled deformation and organ-to-organ apposition redistribute load and create geometry-dependent constraints. The principle of least action is used here as a heuristic first-principles lens for long-term optimization, not as a literal variational proof of pelvic floor evolution. We therefore distinguish classical mechanical action from the broader biological concept of cumulative mechanical cost. The hypothesis predicts that a physiologically stable pelvic floor should show coordinated rather than independent organ displacement under loading, increasing or preserved geometric constraint during transient rises in intra-abdominal pressure, and lower sustained tissue tension than would be required by a purely suspensory model. Loss of these relationships should be associated with abnormal load concentration, relative organ displacement, and pelvic floor dysfunction. These predictions can be tested using dynamic imaging, computational modeling,

experimental biomechanics, and prospective clinical studies. The proposed framework is intended to complement rather than replace established anatomical support theories and to shift reconstructive thinking from anatomical repositioning alone toward restoration of system-level biomechanical stability.

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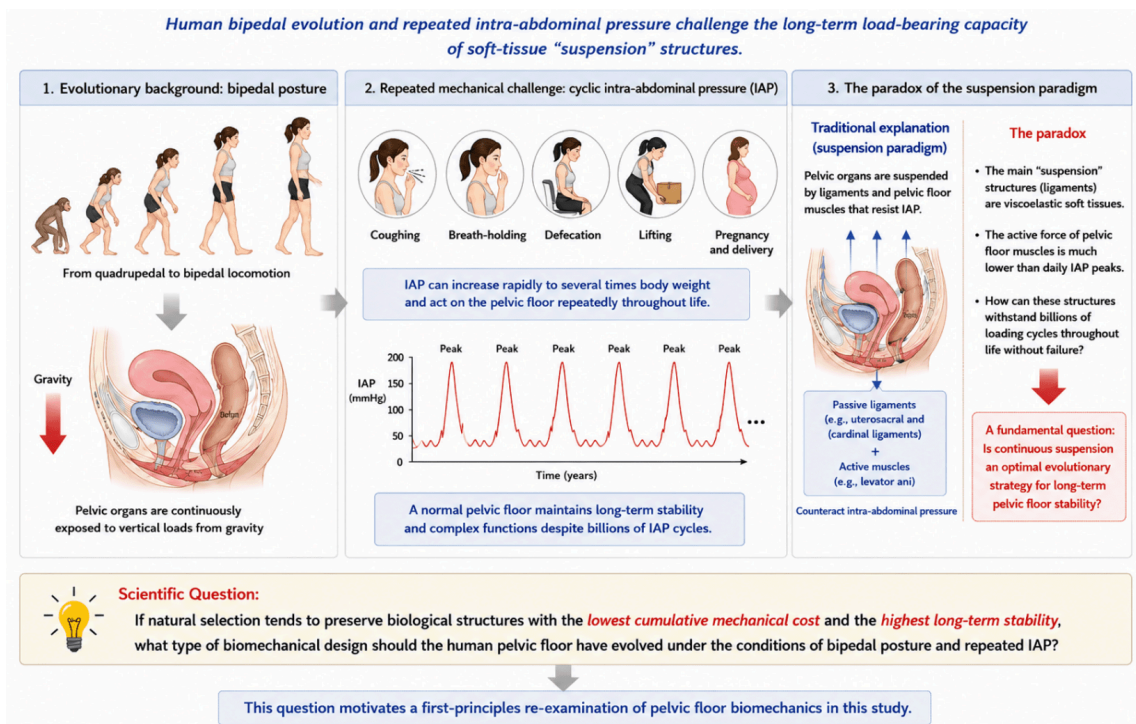
## 1. Are We Asking the Right Biomechanical Question?

The human pelvic floor is an unusual load-bearing biological system. With habitual bipedal posture, the pelvic viscera are repeatedly exposed to gravity and to transient increases in intra-abdominal pressure during coughing, straining, defecation, lifting, pregnancy, and childbirth. Despite this repeated loading, a healthy pelvic floor can remain mechanically stable while supporting continence, evacuation, sexual function, and organ mobility over decades <sup>[1]</sup>.

Pelvic support has traditionally been described in terms of connective-tissue suspension and muscular support, including the uterosacral and cardinal ligament complexes and the levator ani. This framework has shaped both mechanistic thinking and reconstructive surgery <sup>[2][3]</sup>. It is indispensable, but it may not be sufficient as a complete explanation of long-term stability.

Long-term clinical studies show that anatomical correction does not always translate into durable functional recovery, and recurrence and implant-related complications remain clinically relevant <sup>[4][5][6]</sup>. At the same time, uterine suspensory tissues are compliant and viscoelastic rather than rigid cables, and pelvic organs undergo measurable displacement under physiological loading <sup>[2][3][7][8]</sup>. These observations raise a basic question: is the pelvic floor best understood as a system that continuously resists load through tension, or as a coupled system in which geometry itself contributes to stability?

This paper develops the second possibility. We propose that dynamic geometric constraint may reduce the amount of sustained tissue tension and active muscular work required to maintain stability. The aim is not to reject established support theories, but to formulate a broader mechanical hypothesis capable of linking pelvic floor evolution, normal function, dysfunction, and reconstructive strategy. The conceptual problem motivating this hypothesis is summarized in Figure 1.



**Figure 1.** The paradox of Pelvic Floor Stability: Why the Traditional Suspension Paradigm Is Insufficient

## 2. Why Is a Complementary Framework Needed?

Clinical outcomes expose a distinction between anatomical position and function. Correction of prolapse can restore organ position without uniformly restoring urinary, bowel, or sexual function. Different suspension procedures can achieve satisfactory early anatomy yet still show recurrence over time, while implant-based reinforcement can introduce new complications [4][5][6]. These findings do not demonstrate that suspension is unimportant; they show that anatomy alone is an incomplete endpoint.

Dynamic imaging and computational studies increasingly portray the pelvic floor as an integrated, deformable system rather than a set of independent supporting elements [7][8][9][10]. Under load, organs and support structures move relative to one another, alter contact relationships, and redistribute stress. A theory of long-term stability should therefore explain not only which structures provide support, but also how their spatial relationships organize force transmission.

The gap addressed here is thus a systems-level one. If the pelvic floor is mechanically stable because multiple structures cooperate, then the relevant unit of analysis may be the configuration of the system rather than the strength of any single ligament, muscle, or implant.

### 3. An Evolutionary Mechanical Paradox

At first glance, suspension appears to be an intuitive solution to pelvic support: pelvic organs lie above the pelvic outlet and are exposed to downward loading, so stronger suspensory tissues might seem advantageous. Yet the actual support system is compliant and mobile. From an evolutionary biomechanics perspective, this creates a useful paradox. Why would a system exposed to lifelong cyclic loading retain deformable tissues and substantial physiological mobility rather than evolve toward a more rigid, high-tension suspension apparatus?

Natural selection does not optimize a single engineering variable, and it should not be described as consciously “choosing” a design. Nevertheless, traits that improve reproductive success and functional durability can be retained under competing constraints. Human pelvic evolution is known to involve biomechanical trade-offs related to locomotion, childbirth, and pelvic floor function [\[11\]\[12\]\[13\]](#). For a repeatedly loaded biological system, three general performance demands are especially relevant: tolerance of cyclic loading, maintenance of mechanical stability, and limitation of cumulative tissue cost.

The hypothesis developed here is that long-term pelvic floor stability may depend partly on reducing the need for continuous high tissue tension. If so, the evolutionary question changes from “How strong must the suspension be?” to “How can geometry and controlled deformation reduce the load that suspension must carry?”

| Long-term requirement          | Mechanical implication                                     |
|--------------------------------|------------------------------------------------------------|
| Tolerance of cyclic loading    | Limit fatigue, creep, and cumulative microdamage           |
| Maintenance of stability       | Avoid progressive structural instability                   |
| Low cumulative mechanical cost | Reduce sustained tissue stress and unnecessary active work |

**Table 1.** General performance demands for a biological system exposed to long-term cyclic loading.

### 4. The Principle of Least Action as a Heuristic, Not a Proof

The classical principle of least action states that the physical trajectory of a system makes the action stationary, where action is defined from the time integral of a Lagrangian. That formal principle applies

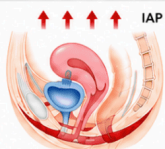
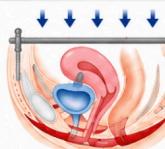
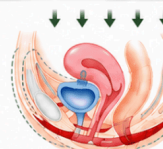
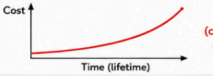
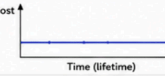
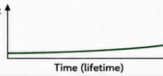
to specified physical systems and boundary conditions. Evolution by natural selection is not itself a classical mechanical trajectory, and it would be incorrect to claim that biological evolution literally minimizes mechanical action.

Here, the principle is used more modestly: as a first-principles heuristic that directs attention from instantaneous strength toward accumulated cost over time. This distinction is essential. In the present framework, “cumulative mechanical cost” refers broadly to sustained tissue stress, repeated strain, active muscular work, fatigue, creep, and microdamage across many loading cycles. It is not asserted to be mathematically identical to classical action.

This framing leads to a testable question rather than a proof: among mechanically feasible pelvic floor configurations, would a geometry-dependent system achieve comparable stability with less sustained tissue tension or active work than a model based predominantly on continuous suspension? If the answer is no, the proposed framework loses one of its central advantages.

## **5. Three Candidate Strategies for Long-Term Stability**

For conceptual comparison, long-term stabilization can be represented by three idealized strategies: continuous load bearing, rigid fixation, and geometric locking. Real biological systems can combine all three; the categories are therefore analytical extremes rather than mutually exclusive anatomical states. These idealized strategies are compared in Figure 2.

| Comparison of continuous load-bearing (suspension), rigid fixation, and geometric locking (dynamic geometric constraint).                                                                                                                                                                                           |                                                                                                                                                                                      |                                                                                                                                                                                           |                                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                     | Strategy A<br>Continuous Load-Bearing<br>(Suspension Paradigm)                                                                                                                       | Strategy B<br>Rigid Fixation                                                                                                                                                              | Strategy C<br>Geometric Locking<br>(Dynamic Geometric Constraint)                                                                                                                                           |
|  Core mechanism                                                                                                                                                                                                                    | Pelvic organs are continuously suspended by ligaments and pelvic floor muscles that resist intra-abdominal pressure (IAP).                                                           | Stability is achieved by mechanically restricting displacement through rigid fixation.                                                                                                    | Organs and supporting structures form a dynamic geometric constraint; stability arises from geometry rather than continuous load-bearing.                                                                   |
|  Schematic illustration (normal state)                                                                                                                                                                                             | <br>Stability relies on tension in ligaments and muscles.                                           | <br>Stability relies on mechanical fixation that restricts displacement.                                 | <br>Stability arises from geometric constraint and load redistribution.                                                  |
|  Response to increased intra-abdominal pressure (IAP)                                                                                                                                                                              |  Ligaments and muscles bear greater tension; structures strain and risk fatigue, creep, or failure. |  Fixation resists displacement; stress concentrates at fixation points.                                  |  Organs allow limited coordinated movement; contact area increases, constraint enhances, and load is redistributed.      |
|  Mechanical characteristics                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Requires continuous tension</li> <li>High energy demand</li> <li>Tissue fatigue and creep over time</li> <li>Susceptible to damage</li> </ul> | <ul style="list-style-type: none"> <li>Low energy demand</li> <li>High local stress concentration</li> <li>Risk of implant-related complications</li> <li>Limited adaptability</li> </ul> | <ul style="list-style-type: none"> <li>Low energy demand</li> <li>Stress distributed through geometry</li> <li>High adaptability and self-stabilization</li> <li>Lower risk of long-term failure</li> </ul> |
|  Evolutionary feasibility                                                                                                                                                                                                          | <b>Low</b><br>High cumulative cost, low long-term reliability                                                                                                                        | <b>Medium</b><br>Acceptable in specific situations, but not ideal for lifelong loading                                                                                                    | <b>High (Hypothesized)</b><br>Lowest cumulative cost and highest long-term stability                                                                                                                        |
|  Cumulative mechanical cost over a lifetime                                                                                                                                                                                        | <br>Cost ↑<br>Time (lifetime) →<br>High (continues to rise)                                         | <br>Cost ↑<br>Time (lifetime) →<br>Moderate (relatively stable)                                          | <br>Cost ↑<br>Time (lifetime) →<br>Low (minimal increase)                                                                |
|  Summary                                                                                                                                                                                                                           | Continuous load-bearing is mechanically costly and unlikely to be the optimal evolutionary strategy for long-term pelvic floor stability.                                            | Rigid fixation can provide short-term stability but is not ideal for lifelong adaptability and carries potential risks.                                                                   | Geometric locking offers a biomechanically efficient, adaptable, and potentially evolutionarily advantageous strategy for long-term pelvic floor stability.                                                 |
|  This comparison suggests that geometric locking may represent a potentially evolutionarily advantageous strategy under the principle of least action: minimizing cumulative mechanical cost while maximizing long-term stability. |                                                                                                                                                                                      |                                                                                                                                                                                           |                                                                                                                                                                                                             |

**Figure 2.** Three Fundamental Biomechanical Stabilization Strategies for the Pelvic Floor

Continuous load bearing maintains position through sustained tensile or compressive forces. In a biological tissue, long-term loading can be accompanied by viscoelastic deformation, creep, fatigue, and microdamage. A purely suspensory interpretation of pelvic support emphasizes this mode.

Rigid fixation limits motion to preserve position. It can provide high instantaneous stability, but excessive rigidity in a living system may create stress concentration, interface loading, and loss of physiological mobility. This makes rigid fixation an imperfect model for a pelvic floor that must accommodate filling, evacuation, sexual function, pregnancy, and childbirth.

Geometric locking, as defined in this paper, is stability produced partly by spatial configuration, contact, and constraint. Once an appropriate configuration is established, external loading can be redistributed across interfaces and supporting structures rather than being carried predominantly as sustained tension by one element. Engineering analogies such as arches or interlocking joints illustrate the concept, but they should not be taken as direct anatomical equivalents.

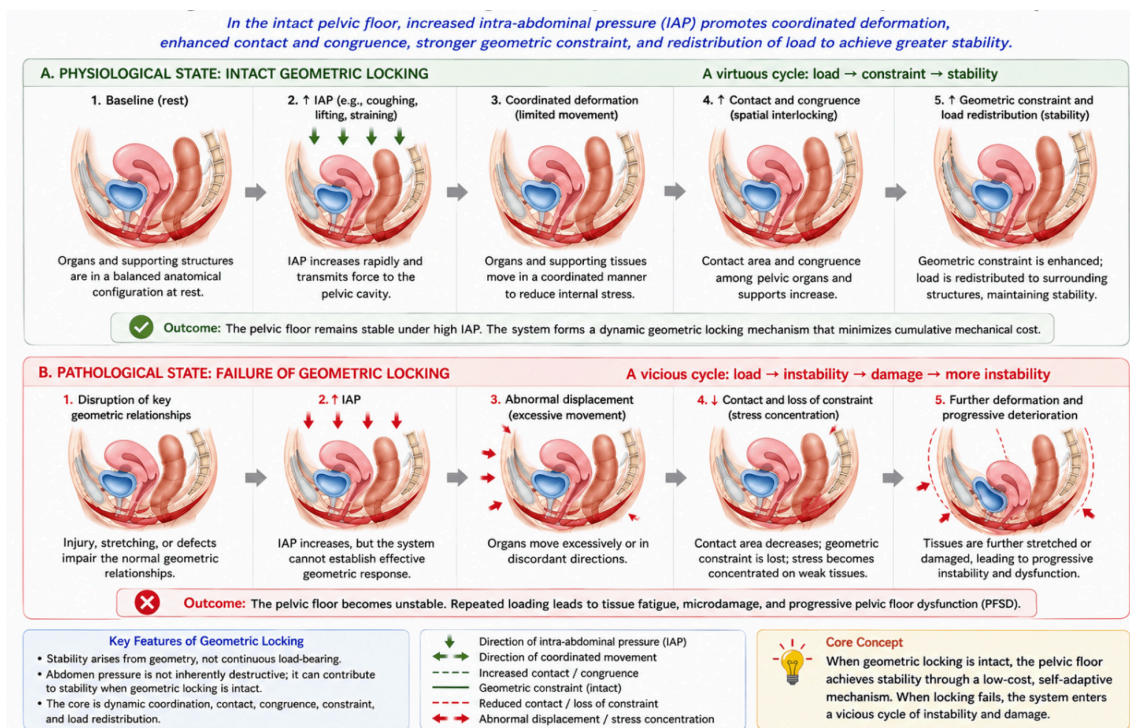
## 6. Geometric Locking as a Pelvic Floor Hypothesis

Re-examined from this perspective, several pelvic floor features are compatible with a geometry-dependent contribution to stability. The bladder, vagina, uterus, rectum, levator plate, perineal body, and apical support structures occupy a confined space and interact mechanically. Previous work has described pelvic geometry and dynamic mechanical equilibrium as potentially relevant to pelvic floor function [9][10].

We hypothesize that, in a physiologically stable state, transient increases in intra-abdominal pressure do not simply drive each organ independently downward against suspensory resistance. Instead, controlled deformation and coordinated displacement alter contact relationships among organs and support structures. Apposition may increase, relative sliding may be constrained, and load may be redirected through the coupled configuration. In this sense, limited movement is not necessarily a failure of support; it may be part of the stabilizing mechanism.

The levator plate and perineal body may contribute active and passive boundary conditions, while the cervix and posterior vaginal fornix may help preserve apical geometry. The central claim is therefore not that ligaments or muscles are unnecessary. Rather, their mechanical role may include establishing and maintaining a favorable geometry in which the whole system carries load more efficiently.

This hypothesis also changes the interpretation of intra-abdominal pressure. Pressure remains a potential source of injury, particularly when tissue capacity is exceeded. However, in an intact geometric system, pressure may also contribute to apposition and load redistribution. The pathological transition would occur when the geometry or its boundary conditions are disrupted, so that the same pressure produces abnormal relative displacement and localized stress concentration instead of coordinated system-level stabilization. The proposed physiological and pathological sequences are summarized in Figure 3.



**Figure 3.** How Geometric Locking Works: Dynamic Formation of Geometry-Based Stability

## 7. Testable Predictions and Falsification Criteria

A hypothesis should be specific enough to fail. The geometric-locking framework, therefore, makes the following predictions:

**Prediction 1: coordinated displacement under load.** In healthy participants, dynamic MRI or ultrasound during standardized increases in intra-abdominal pressure should show reproducible, coupled displacement patterns among pelvic organs and support structures rather than independent downward translation. A consistent absence of such coupling would argue against a central premise of the model.

**Prediction 2: geometry-dependent load redistribution.** Finite-element or other computational models that incorporate organ contact and realistic boundary conditions should demonstrate redistribution of stress as contact and geometric constraint increase. If contact-aware models do not reduce local stress or required support tension relative to otherwise comparable suspension-dominant models, the proposed mechanical advantage would not be supported.

**Prediction 3: disruption should precede or accompany stress concentration.** Pelvic floor dysfunction associated with loss of normal geometric relationships should show greater relative organ displacement,

altered contact interfaces, or more localized stress concentrations than mechanically stable controls. These variables should be measurable independently of conventional organ–position staging.

**Prediction 4: restoration of geometry should add explanatory value.** After reconstructive treatment, restoration of geometry-dependent relationships should correlate with functional outcomes and recurrence risk beyond anatomical position alone. Failure to provide incremental predictive value over established measures would limit the clinical relevance of the framework.

**Prediction 5: lower sustained mechanical demand.** For a given level of organ stability, a model incorporating geometric locking should require less sustained ligament tension and/or active muscular work than a model in which stability is produced predominantly by continuous suspension. This prediction can be evaluated computationally and, where feasible, experimentally. A structured validation and falsification framework is summarized in Figure 4.



Figure 4. Testable Predictions and Falsification Framework of the Geometric-Locking Hypothesis

## 8. Low Mechanical Cost as a Route to Long-Term Stability

The proposed advantage of geometric locking is not low energy expenditure as an end in itself. The relevant biological outcome is durable function. Repeatedly loaded tissues face fatigue, creep, stress

concentration, and cumulative microdamage. A configuration that reduces sustained high tension or unnecessary active work could, in principle, reduce the rate at which such damage accumulates.

This argument should remain probabilistic rather than absolute. Tissue adaptation, repair, neuromuscular control, hormonal status, aging, childbirth injury, and connective-tissue properties all influence pelvic floor durability. Geometric organization is therefore proposed as one layer of the system, not a universal explanation for every form of pelvic floor dysfunction.

Within that boundary, the hypothesis offers a coherent interpretation: active muscle and connective-tissue support help establish a mechanically favorable configuration; the configuration then shares and redirects load; and repeated loading becomes more damaging when the configuration or its constraints are lost. This sequence can be examined rather than assumed.

## **9. Implications for Pelvic Floor Reconstruction**

If geometric constraint contributes materially to normal stability, reconstructive success should not be judged by organ position alone. A repair that restores position but creates non-physiological force paths, excessive focal tension, or restricted mobility could be anatomically satisfactory yet mechanically suboptimal.

The corresponding surgical principle would be to restore the conditions for physiological load sharing: appropriate organ relationships, support axes, compliant constraint, and coordinated movement. This does not imply abandoning suspension procedures or implants. It implies evaluating them according to the mechanical system they create after reconstruction.

This perspective is consistent with the broader shift from static anatomical repair toward dynamic biomechanical equilibrium described in recent pelvic floor literature <sup>[10]</sup>. Whether geometry-based metrics can improve procedure selection or predict long-term outcomes remains an empirical question.

## **10. Limitations and Reasons the Hypothesis Could Be Wrong**

The present article is conceptual and does not provide new experimental or clinical data. Several claims are therefore provisional. First, the analogy between least action and evolutionary optimization is heuristic; no mathematical derivation is offered that maps classical action onto biological fitness or tissue damage. Second, geometric locking has not yet been quantified as a single measurable variable,

and the relative contributions of contact, friction, tissue stiffness, muscle activation, and ligament tension remain unresolved.

Third, pelvic floor anatomy and tissue properties vary substantially among individuals and across age, parity, hormonal status, childbirth history, and disease. A configuration that is mechanically favorable in one person may not be optimal in another. Fourth, engineering analogies such as arches and interlocking structures can clarify a principle but can also oversimplify living, viscoelastic, actively controlled tissues.

Finally, the framework would be weakened if high-quality dynamic imaging and contact-aware biomechanical models show that normal pelvic stability is adequately explained by established suspensory and muscular mechanisms without a meaningful contribution from geometry-dependent constraint. It would also lose clinical relevance if proposed geometric metrics fail to improve prediction of symptoms, recurrence, or treatment response beyond established anatomical and functional measures.

## 11. Conclusion

This Article proposes a complementary hypothesis for understanding pelvic floor stability. Instead of treating the pelvic floor primarily as a set of structures that suspend organs against load, we ask whether long-term stability also emerges from dynamic geometry: coordinated deformation, contact, boundary constraints, and system-level load redistribution.

The principle of least action is used only as a heuristic that motivates attention to cumulative mechanical cost; it is not presented as a physical proof of evolutionary history. The scientific value of the framework, therefore, depends on its predictions. Dynamic imaging should reveal coordinated geometry-dependent behavior; computational models should quantify whether contact and constraint reduce sustained mechanical demand; and prospective studies should determine whether restoration of these relationships predicts function and durability beyond anatomical repositioning alone.

If these predictions are supported, pelvic floor reconstruction may be better framed as restoration of a stable biomechanical system rather than correction of organ position alone. If they are not supported, the geometric-locking hypothesis should be revised or rejected. That falsifiability is central to the purpose of the model.

## Statements and Declarations

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### *Potential Competing Interests*

The authors declare no competing interests.

### *Ethics*

This article presents a conceptual biomechanical hypothesis and does not report new research involving human participants, identifiable patient information, human tissue, or animals. New ethics approval and informed consent were therefore not applicable to this manuscript.

### *Data Availability*

No new datasets were generated or analyzed for this hypothesis article. The article synthesizes and interprets previously published literature.

### *Author Contributions*

- Jihong Shen and Tingqiang Yao: Conceptualization and development of the core theoretical framework.
- Shengpei Pang: Writing – Original Draft; Writing – Review & Editing.
- Ling Li and Jiaying Rao: Conceptual analysis; critical review and correction of the manuscript.

All authors reviewed and approved the final submitted version and confirm the contribution statement before posting.

## Use of Generative AI

During manuscript preparation, the authors used OpenAI ChatGPT (GPT-5.6 Sol) for English-language editing, grammatical correction, structural organization, and assistance in producing draft conceptual scientific illustrations from author-specified content. The scientific concepts, hypotheses, interpretation of the literature, references, figure logic, and final wording remain the responsibility of the human authors, who reviewed and approved the manuscript content.

## References

1. <sup>a</sup>Du H, Yang M, Qi X, et al. (2025). "Comprehensive Analysis of the Biomechanical Research of Pelvic Organ Prolapse: A Scientometric Approach." *J Multidiscip Healthc*. 18:1249–1268. doi:[10.2147/JMDH.S473196](https://doi.org/10.2147/JMDH.S473196).
2. <sup>a</sup><sup>b</sup>Luo J, Swenson CW, Betschart C, et al. (2023). "Comparison of in Vivo Visco-Hyperelastic Properties of Uterine Suspensory Tissue in Women with and without Pelvic Organ Prolapse." *J Mech Behav Biomed Mater*. 137:105544. doi:[10.1016/j.jmbbm.2022.105544](https://doi.org/10.1016/j.jmbbm.2022.105544).
3. <sup>a</sup><sup>b</sup>Luo J, Smith TM, Ashton-Miller JA, et al. (2014). "In Vivo Properties of Uterine Suspensory Tissue in Pelvic Organ Prolapse." *J Biomech Eng*. 136(2):021016.
4. <sup>a</sup><sup>b</sup>Vigna A, Barba M, Frigerio M. (2024). "Long-Term Outcomes (10 Years) of Sacrospinous Ligament Fixation for Pelvic Organ Prolapse Repair." *Healthcare*. 12(16):1611. doi:[10.3390/healthcare12161611](https://doi.org/10.3390/healthcare12161611).
5. <sup>a</sup><sup>b</sup>Lo TS, et al. (2025). "Long-Term Outcome of Anterior-Apical Mesh (Surelift) Versus Anterior Colporrhaphy and Sacrospinous Ligament Fixation in Advanced Pelvic Organ Prolapse Surgery." *Int Urogynecol J*. 36(4): 857–866. doi:[10.1007/s00192-025-06105-1](https://doi.org/10.1007/s00192-025-06105-1).
6. <sup>a</sup><sup>b</sup>Kato C, Kuwata T, Kashiara H, et al. (2024). "Long-Term Outcomes of Transvaginal Mesh Surgery for Pelvic Organ Prolapse at a Single Center in Japan." *Int J Urol*. doi:[10.1111/iju.15630](https://doi.org/10.1111/iju.15630).
7. <sup>a</sup><sup>b</sup>Xu Z, Chen N, Wang B, et al. (2023). "Creation of the Biomechanical Finite Element Model of Female Pelvic Floor Supporting Structure Based on Thin-Sectional High-Resolution Anatomical Images." *J Biomech*. 146: 111399. doi:[10.1016/j.jbiomech.2022.111399](https://doi.org/10.1016/j.jbiomech.2022.111399).
8. <sup>a</sup><sup>b</sup>Yang M, Chen C, Wang Z, et al. (2024). "Finite Element Analysis of Female Pelvic Organ Prolapse Mechanism: Current Landscape and Future Opportunities." *Front Med*. 11:1342645. doi:[10.3389/fmed.2024.1342645](https://doi.org/10.3389/fmed.2024.1342645).
9. <sup>a</sup><sup>b</sup>Ma L, Zhao Y, Cheng Y, Shen W. (2024). "Research Status on Pelvic Geometric Configuration Characteristics of Female Pelvic Floor Dysfunction." *Int J Med Radiol*. 47(1):97–100. doi:[10.19300/j.2024.Z20760](https://doi.org/10.19300/j.2024.Z20760).

10. <sup>a, b, c</sup>Tian D, Luo Q, Wang X, et al. (2025). "Dynamic Biomechanical Equilibrium in Pelvic Organ Prolapse: From Mechanistic Insights to Precision Reconstruction." *Front Med.* **12**:1637133. doi:[10.3389/fmed.2025.1637133](https://doi.org/10.3389/fmed.2025.1637133).
11. <sup>Δ</sup>Stansfield E, Kumar K, Mitteroecker P, et al. (2021). "Biomechanical Trade-Offs in the Pelvic Floor Constraint the Evolution of the Human Birth Canal." *Proc Natl Acad Sci U S A.* **118**(16):e2023344118. doi:[10.1073/pnas.2023344118](https://doi.org/10.1073/pnas.2023344118).
12. <sup>Δ</sup>Stansfield E, Fischer B, Grunstra NDS, et al. (2021). "The Evolution of Pelvic Canal Shape and Rotational Birth in Humans." *BMC Biol.* **19**(1). doi:[10.1186/s12915-021-01120-2](https://doi.org/10.1186/s12915-021-01120-2).
13. <sup>Δ</sup>Mitteroecker P, Fischer B. (2024). "Evolution of the Human Birth Canal." *Am J Obstet Gynecol.* **230**(3):S841–S855. doi:[10.1016/j.ajog.2022.09.010](https://doi.org/10.1016/j.ajog.2022.09.010).

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**Potential competing interests:** No potential competing interests to declare.