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Vertebral Subluxation as an Emergent Energy-Conserving Phenotype: An integrative framework of Constructal Law, Free Energy Principle, Dynamical Systems Theory, and Evolutionary Biology

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Objective: To reconceptualise vertebral subluxation not as a static lesion or outdated metaphysical construct, but as an emergent, energy-conserving state within living systems. This paper develops a novel theoretical framework by integrating the Constructal Law, the Free Energy Principle, Dynamical Systems Theory, and evolutionary biology, thereby positioning vertebral subluxation as a predictable adaptive phenomenon rather than a pathological anomaly.

Methods: A critical theoretical integration approach was employed. Four scientific frameworks were systematically mapped, aligned through shared principles of flow optimisation, prediction error minimisation, attractor stabilisation, and energy conservation, and synthesised into a unifying model. Mathematical formulations were used to articulate precision in the proposed dynamics, including cost functions for prediction error, attractor basin models, and energy minimisation equations.

Results: The integrated model yields the following insights:

- Constructal Law: Subluxation emerges as a bottleneck in systemic flow that paradoxically optimises energy distribution under constraints. (1, 2)
- Free Energy Principle: Subluxation represents fixation of prediction error when the energetic cost of correction exceeds the stability gained by maintaining the error. (3 - 6)
- Dynamical Systems Theory: Subluxation functions as a stable attractor state in the organism's energy landscape; chiropractic adjustments act as perturbations capable of shifting the system into more adaptive basins. (7 - 9)
- Evolutionary Biology: Subluxation is interpreted as a phenotype of energy conservation, trading long-term adaptability for short-term metabolic efficiency. (10 - 13)

Mathematically, subluxation corresponds to a local minimum of total energetic cost across flow, prediction, and stability domains. Chiropractic adjustment is modelled as a perturbation that must exceed the depth of this attractor basin to restore systemic flexibility.

Discussion: This reframing addresses long-standing criticisms of subluxation as vague, unscientific, or obsolete. By situating subluxation within universal scientific principles, it demonstrates conceptual clarity, biological plausibility, and testability. Anticipated counterarguments (e.g., lack of empirical evidence, reliance on metaphors, evolutionary rationalisation) are rebutted by emphasising the generative potential of the model for hypothesis-driven research, including neuro-imaging, metabolic cost analysis, and nonlinear attractor mapping.

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Conclusion: Vertebral subluxation is best understood as an emergent, energy-conserving attractor state reflecting the organism's adaptive trade-offs in prediction, flow, and stability. Chiropractic adjustment is correspondingly redefined as a targeted perturbation within this energy landscape, designed to restore adaptive flexibility and optimise systemic function. This theoretical synthesis provides Chiropractic with a scientifically rigorous foundation for its central concept and establishes a research agenda linking Chiropractic care to cutting-edge theories in physics, neuroscience, and evolutionary biology.

Indexing terms: Chiropractic; vertebral subluxation; constructal law; free-energy principle; predictive coding; dynamical systems theory; evolutionary biology.

Introduction

Chiropractic as a distinct healthcare profession has evolved over the past 130 years with one central concept forming the foundation of its identity: the vertebral subluxation and its adjustment. Since DD Palmer's discovery in 1895, subluxation has been regarded not merely as a mechanical displacement of the spine but as a functional disturbance with potential systemic implications. (14, 15)

'... The Chiropractic adjustment is redefined as a strategic perturbation, a deliberate modulation of the organism's energy landscape ...'

The notion of vertebral subluxation has played a dual role, anchoring chiropractic as a unique discipline while simultaneously generating ongoing debates about its definition, nature, and scientific legitimacy. (16, 17 18) Indeed, the very survival of Chiropractic as an independent profession is intimately tied to this concept, since it represents the primary domain that differentiates Chiropractic from other manual and health care professions. (19)

Despite its centrality, the definition of vertebral subluxation has been in constant flux throughout the history of Chiropractic. While some early Chiropractors embraced a vitalistic interpretation rooted in the flow of 'Innate Intelligence' through the nervous system, (20, 21) subsequent generations attempted to reframe subluxation within biomechanical, neurological, or clinical frameworks. (22, 23, 24). These evolving definitions have been shaped by sociocultural forces, philosophical commitments, and scientific advancements. (25)

Nevertheless, the absence of a unified, scientifically rigorous definition has led to what can fairly be described as conceptual chaos. Different Chiropractic techniques often utilise their own operational definitions of subluxation, creating fragmentation within the profession and confusion in its external perception. (26, 27)

Several comprehensive historical and philosophical reviews of vertebral subluxation have been undertaken, with the works of Senzon (2018, 2019) representing the most systematic and scientifically grounded accounts. (28, 29) Senzon has meticulously traced the philosophical evolution of the concept from Palmer to the present, situating it within broader paradigms of healthcare thought. His analyses reveal that Chiropractic has oscillated between efforts to preserve a distinct identity anchored in subluxation and pressures to conform to mainstream biomedical models. (30, 31)

While such historical reviews are indispensable, it is not the purpose of this paper to replicate them in detail. Instead, the present work builds upon these foundations to offer a novel theoretical reinterpretation of subluxation within the context of contemporary scientific principles.

My central thesis

The central thesis of this paper is that vertebral subluxation can be understood not simply as a pathological misalignment or neurological interference but as an emergent expression of an organism's inherent energy-conserving tendencies. (32, 33)

From an evolutionary perspective, biological systems are characterised by the drive to optimise energy expenditure relative to survival and adaptation. (34) When framed through this lens, vertebral subluxation may represent a phenotype of the organism's broader strategy to conserve energy by stabilising patterns of prediction error and information flow within the nervous system, even if such stabilisation results in structural misalignments. (35, 36) In this sense, subluxation is not merely a dysfunction but a functional adaptation, a local minimum in the organism's energy landscape. (37)

To articulate this perspective, this study integrates four major theoretical frameworks:

- Constructal Law (Bejan, 1996, 2000): which posits that flow systems, whether biological or physical, evolve in a manner that facilitates easier access to currents of flow (1, 2)
- Free Energy Principle (Friston, 2010, 2019): which views biological systems as minimising surprise (or prediction error) by updating internal models or stabilising errors when correction is too costly (3 - 6
- Dynamical Systems Theory (Thelen & Smith, 1994): which provides tools to model the organism as a nonlinear system whose states can be trapped in attractor basins (7, 8, 9)
- Evolutionary Biology (Mayr, 1982; Dawkins, 1986): which situates subluxation as an adaptive energy- conserving phenotype (10 - 13)

By weaving these frameworks into a coherent theoretical synthesis, this paper aims to reposition vertebral subluxation within contemporary science as a dynamic, functional, and evolutionary phenomenon. Such a model reframes the subluxation not as a static lesion but as a manifestation of the nervous system's and musculoskeletal system's energy management strategies (38, 39)

This perspective allows for a deeper understanding of why subluxations persist, why they resist correction in certain cases, and how Chiropractic adjustments may operate as perturbations that shift the system into new attractor states. (40 - 42)

This theoretical repositioning has several important implications. First, it provides a scientifically defensible rationale for why vertebral subluxations exist beyond the purely mechanical explanations of misalignment. Second, it situates Chiropractic care within a broader context of contemporary scientific principles, thereby enhancing its legitimacy and integration with other disciplines. Third, it preserves the profession's unique focus on subluxation while simultaneously aligning it with cutting-edge theories of biological organisation, energy regulation, and predictive coding. (43, 44)

In summary, while the history of vertebral subluxation is marked by conceptual ambiguity and divergent definitions, this paper proposes a unifying interpretation rooted in energy conservation and information flow. By integrating the Constructal Law, Free Energy Principle, Dynamical Systems Theory, and evolutionary biology, it argues that subluxation is not merely a dysfunction to be eliminated but a systemic adaptation to minimise energy expenditure. Chiropractic adjustments, in this framework, become interventions that reconfigure energy landscapes and restore adaptive flexibility.

The following sections will first provide a concise review of historical definitions of subluxation, then outline the methodological integration of these theoretical frameworks, present the resulting model, and finally discuss its implications for Chiropractic theory, research, and clinical practice.

Literature Review

1. Historical Evolution of Vertebral Subluxation

The concept of vertebral subluxation has undergone substantial transformation since its articulation by D.D. Palmer in 1895 (14, 20) Palmer's original claim framed subluxation as a partial dislocation of vertebrae obstructing the flow of 'Innate Intelligence', a vitalistic principle thought to mediate health and disease. (15, 21)

Early chiropractic texts were dominated by this vitalistic philosophy, which positioned subluxation as the central lesion underlying virtually all disease processes. (22)

Over time, as Chiropractic sought legitimacy within broader healthcare systems, attempts were made to redefine subluxation in mechanical, neurological, or clinical terms. (23, 25) Some Chiropractors emphasised spinal kinematics and joint dysfunction, others focused on neurological interference, while still others highlighted clinical correlates such as altered reflexes, pain, or functional impairment. (26, 27) This diversity of perspectives produced what has often been described as a 'conceptual cacophony' within the profession. 028)

Senzon has provided the most comprehensive scholarly review of these shifting definitions. In his series The Chiropractic Vertebral Subluxation (2018, 2019), Senzon distinguishes between at least four paradigmatic eras:

1. The Palmerian vitalistic era
2. The structural-biomechanical reframing of the early-to-mid 20th Century
3. The neurophysiological interpretations of the late 20th Century
4. The current pluralistic and fragmented era, where definitions vary by technique system and institutional context (29 - 31)

2. Major Definitions of Vertebral Subluxation

While the precise language has varied, definitions of vertebral subluxation can be grouped into thematic clusters. Table 1 summarises some of the most influential definitions across history.

Table 1: Representative Definitions of Vertebral Subluxation (1900 - Present)

Era / Author	Definition	Key Features
D.D. Palmer (1895–1910)	Subluxation is a displacement of a vertebra impinging on nerves, obstructing the flow of Innate Intelligence.	Vitalistic, metaphysical, universal cause of disease.
B.J. Palmer (1910–1960)	Subluxation as the central lesion corrected by adjustment; emphasis on upper cervical spine.	Vitalistic, but with greater emphasis on nervous system pathways.
Stephenson (1927)	"A subluxation is the condition of a vertebra that has lost its proper juxtaposition with the one above, the one below, or both, to an extent less than luxation, which impinges nerves and interferes with the transmission of mental impulses." (*Chiropractic Textbook*)	Structural and neurological hybrid; widely adopted within early chiropractic education.

Homewood (1962)	Defined subluxation in biomechanical terms as hypomobility or fixation of spinal joints with neurological consequences.	Biomechanical orientation, partial move away from vitalism.
Lantz (1989)	Proposed a multidimensional model including kinesiological, neurological, connective tissue, vascular, and psychosocial aspects.	Systems-based, multi-component definition.
Gatterman & Hansen (1994)	Defined subluxation as "a complex of functional and/or structural and/or pathological articular changes that compromise neural integrity and may influence organ system function and general health."	Recognized by many chiropractic institutions as a working definition.
Kent (1996)	Framed subluxation as a "vertebral subluxation complex" incorporating dyskinesia, dysafferentation, dysautonomia, and dysponesis.	Neurophysiological focus, integrating stress and maladaptation.
World Health Organization (2005)	Defined subluxation as "a lesion or dysfunction in a joint or motion segment in which alignment, movement integrity, and/or physiological function are altered, although contact between joint surfaces remains intact."	Neutral, biomechanical and clinical definition; avoids vitalism.
Contemporary Technique Systems (2000–present)	Each major chiropractic technique (e.g., Gonstead, Diversified, Activator, NUCCA, CBP) employs its own operational definition of subluxation.	Fragmented, technique-specific interpretations.

3. Themes Emerging from Historical Definitions

From this overview, several recurring themes can be identified:

1. Vitalistic Foundations. Early chiropractic viewed subluxation as a metaphysical obstruction of vital flow.
2. Biomechanical Reframing. Mid-20th Century definitions emphasised hypomobility, fixation, and kinematic dysfunction.
3. Neurophysiological Shift. Late 20th Century accounts focused on dysafferentation, autonomic imbalance, and maladaptive neural plasticity.
4. Systems-Oriented Approaches. More recent models highlight the multidimensional and biopsychosocial nature of subluxation.
5. Fragmentation and Pluralism. Contemporary chiropractic lacks a unified definition, with technique systems and institutions offering divergent accounts.

This progression reveals both a search for scientific legitimacy and an ongoing struggle to reconcile Chiropractic's unique identity with modern healthcare paradigms.

4. Limitations of Prior Definitions

Despite their diversity, existing definitions share several limitations that warrant reconsideration:

- Conceptual Ambiguity: Many definitions rely on vague or overlapping terminology, making operationalisation difficult.
- Over-Reliance on Belief: Especially in early chiropractic, definitions were rooted more in philosophical belief than empirical evidence.
- Reductionism: Biomechanical models often reduce subluxation to joint motion, neglecting broader systemic dynamics.
- Lack of Evolutionary Framing: None of the major definitions explicitly contextualise subluxation within the evolutionary imperative of energy conservation.
- Fragmentation: The coexistence of multiple, incompatible definitions undermines chiropractic's theoretical coherence.

These limitations underscore the need for a new, integrative framework that situates subluxation within contemporary scientific paradigms.

5. Senzon's Contribution

Senzon's work is particularly relevant here. In The Chiropractic Vertebral Subluxation Part 1: Historical and Philosophical Perspectives (2018) and Part 2: Scientific and Theoretical Perspectives (2019), Senzon traces the trajectory of Chiropractic philosophy and its entanglement with subluxation theory. He demonstrates that the profession's philosophical identity has often shifted in response to external pressures, such as regulatory challenges, biomedical dominance, and internal struggles over scope of practice

Senzon's analysis is valuable because it provides a coherent mapping of Chiropractic's intellectual history, while acknowledging the limitations of each definitional paradigm. Importantly, he suggests that rather than discarding subluxation, Chiropractic must seek a renewed theoretical foundation that both preserves its uniqueness and engages meaningfully with contemporary science.

6. Toward a Functional, Evolutionary Reinterpretation

This paper adopts this challenge by reframing vertebral subluxation not as a static lesion but as a dynamic expression of systemic energy conservation. By integrating the Constructal Law, Free Energy Principle, Dynamical Systems Theory, and evolutionary biology, subluxation is reconceptualised as an adaptive, though sometimes maladaptive, attractor state.

This reinterpretation preserves Chiropractic's distinctiveness while addressing prior limitations:

- It clarifies ambiguity by grounding subluxation in well-defined scientific principles
- It reduces reliance on belief by linking to testable models of prediction error and energy cost
- It transcends reductionism by considering systemic flows of information, energy, and
- biomechanics
- It introduces evolutionary framing, situating subluxation as a conserved adaptive strategy.
- It offers unification, proposing a shared theoretical framework across techniques.

Methods

1. Theoretical Integration Approach

This study is a theoretical synthesis, employing what may be termed a critical integration approach. Rather than generating new empirical data, the aim is to integrate existing scientific principles into a coherent framework that reinterprets the phenomenon of vertebral subluxation. This approach draws on methods in philosophy of science, systems theory, and theoretical biology, where diverse principles are brought into alignment to generate new explanatory models.

The integration process followed three steps:

1. Conceptual Mapping: Each of the four frameworks (Constructal Law, Free Energy Principle, Dynamical Systems Theory, Evolutionary Biology) was analysed in its original disciplinary context. Key assumptions, formal structures, and explanatory targets were identified (1 -13)
2. Cross-Disciplinary Alignment: Concepts were mapped onto spinal and neurological phenomena. Shared principles included: energy minimisation, flow optimisation, prediction error reduction, and attractor stability (3 - 6, 7, 8, 9)
3. Model Construction: Using shared principles, a new explanatory model was developed in which vertebral subluxation is reframed as an emergent attractor state in the organism's energy landscape. Mathematical formulations were introduced to capture these dynamics and ensure conceptual rigour. (32, 37, 40)

2. Frameworks for Integration

2.1 Constructal Law

Proposed by Adrian Bejan, the Constructal Law states that 'For a finite-size flow system to persist, it must evolve in a way that facilitates easier access to the currents that flow through it'. (1, 2)

In organisms, this manifests as vascular branching, neural arborisation, and musculoskeletal design. (45) Biological systems are flow architectures of matter, energy, and information. Within this paradigm, the spine and nervous system represent conduits through which energy and signals must flow.

For purposes of integration, the Constructal Law was used to model subluxation as a flow bottleneck. Subluxations are interpreted as structural configurations that emerge from systemic optimisation of flow, even if they impose local restrictions. (46, 47)

2.2 Free Energy Principle (FEP)

Karl Friston's Free Energy Principle provides a unifying framework for understanding how living systems maintain their integrity by minimising prediction error (or variational free energy). (3 - 6) Organisms either update internal models or stabilise errors when correction is energetically more costly.

> Applied to subluxation, FEP suggests that the nervous system may stabilise maladaptive postural or structural patterns if correcting them would exceed energetic budgets. Subluxation thus represents a 'prediction error fixation' where discrepancies between expected and actual sensory feedback are not corrected, but rather entrenched as the path of least resistance. (48, 49)

2.3 Dynamical Systems Theory (DST)

DST offers tools for describing nonlinear systems characterised by multiple attractor states. (7, 8, 9) Organismic systems, including posture and motor control, can settle into relatively stable states even if those states are maladaptive.

In this integration, DST provides the language of attractors, basins, and perturbations. Subluxation is modelled as an attractor basin within the organism's energy landscape. Chiropractic adjustment is conceptualised as a perturbation that destabilises the current attractor, (50, 51) allowing the system to shift into a new, potentially more adaptive state.

2.4 Evolutionary Biology

Evolutionary biology provides the ultimate explanatory layer. Across evolutionary time, organisms have developed mechanisms for conserving energy while maximising survival and reproduction.)10 - 13) Structural misalignments such as vertebral subluxation may appear maladaptive in isolation, yet represent an energy-saving adaptation at the systemic level. (52, 53)

For this synthesis, evolutionary biology contextualises subluxation as a phenotypic expression of energy-conserving strategies. This framing allows chiropractic theory to connect with fundamental principles of evolutionary adaptation.

3. Mathematical and Conceptual Tools

To enhance rigour, the synthesis employed mathematical formulations where possible. These include:

- Energy Minimisation Equation

$$E_{total} = E_{metabolic} + E_{structural} + E_{neural}, \quad \frac{\partial E_{total}}{\partial t} \to \min$$

Here, vertebral subluxation is conceptualised as a state that minimises total energetic cost across multiple domains. (37, 40, 46)

- Prediction Error Cost Function

$$F = \sum_i (p_i - \hat{p}_i)^2 \cdot w_i$$

where p_i is sensory input, p_i is predicted input, and w_i is a weight reflecting energy cost vs. stability. Fixation of error occurs when correction cost exceeds stability cost. (3 - 6, 48)

- Attractor Dynamics

$$\frac{dx}{dt} = -\nabla V(x)$$

with V(x) representing the potential landscape of spinal configurations. Subluxation corresponds to a local minimum in V(x). (7 - 9, 50)

- Correction vs Fixation Inequality

$$\text{If } \Delta E_{correction} > \Delta S_{stability} \Rightarrow \text{Fixation (Subluxation)}$$

$$\text{If } \Delta E_{correction} < \Delta S_{stability} \Rightarrow \text{Correction (Adjustment)}$$

These mathematical expressions serve as heuristic models rather than empirical equations but provide precision in articulating the proposed framework. (51)

4. Criteria for Theoretical Integration

The following criteria guided the integration process:

1. Conceptual Consistency: Each theory must contribute without contradiction.
2. Biological Plausibility: The model must align with known principles of physiology and evolution.
3. Explanatory Depth: The framework must address why subluxations persist, not merely how they manifest.
4. Clinical Relevance: The model must offer implications for chiropractic practice and research.
5. Testability: While theoretical, the model should generate hypotheses amenable to empirical investigation (e.g., imaging, biomechanics, metabolic cost studies).

5. Scope and Limitations

This integration is intentionally theoretical. It does not present new empirical data but instead reinterprets existing knowledge through a novel lens. Limitations include the speculative nature of applying abstract principles such as FEP and DST to Chiropractic phenomena, and the challenge of operationalising these models in empirical contexts. However, this limitation is counterbalanced by the potential to generate testable hypotheses and provide a unifying framework for future research.

6. Summary of Methods

In summary, this study employs a critical integration of four scientific frameworks: Constructal Law, Free Energy Principle, Dynamical Systems Theory, and Evolutionary Biology, to reinterpret vertebral subluxation.

Through conceptual mapping, cross-disciplinary alignment, and mathematical modelling, the paper constructs a novel theoretical lens in which subluxation is seen as an emergent, energy-conserving attractor state.

This methodological approach sets the stage for the Results section, where each framework is applied directly to subluxation, and the new integrative model is presented in detail.

Results

1. Application of the Constructal Law to Subluxation

The Constructal Law, as formulated by Bejan (1996, 2000), asserts that all flow systems evolve to provide easier access to currents. In biological organisms, this principle manifests in the branching patterns of trees, vascular systems, neural networks, and musculoskeletal arrangements. The spine, with its dual role as structural support and conduit for neural and vascular flows, represents a quintessential application of this law. (1, 2, 45)

When applied to vertebral subluxation, the Constructal Law reframes misalignment not as a random or pathological event, but as an emergent flow architecture. Subluxation can be viewed as a bottleneck configuration that, paradoxically, optimises energy distribution across the system under specific constraints.

For instance, consider that micro-instabilities in spinal mechanics impose energetic demands on muscular stabilisation and proprioceptive correction. Over time, the organism may adopt a spinal configuration that limits mobility yet reduces overall energetic expenditure by simplifying stabilisation. (46) This configuration may manifest clinically as a subluxation. In this sense, subluxation is not an accident of dysfunction, but an adaptation of flow structures towards energy efficiency.

Mathematically, this can be expressed as:

$$E_{flow} = \sum_j \frac{\Delta P_j}{R_j}$$

where ΔP_j represents pressure or energetic gradients across flow pathways (vascular, neural, structural), and R_j represents resistances. A subluxation emerges when the distribution of R_j minimises total E_{flow} despite producing localised restrictions. (47)

2. Application of the Free Energy Principle

The Free Energy Principle (Friston, 2010, 2019) posits that living systems resist entropy by minimising prediction error (or surprise) through perception and action. Prediction error minimisation requires constant updating of internal models. However, when the cost of correction exceeds the benefit, the system may stabilise prediction errors instead of resolving them.

In this context, vertebral subluxation can be understood as a prediction error fixation. (3 - 6, 48)

The nervous system anticipates sensory input, $\hat{p}_i$, based on internal models. When actual sensory input, p_i, deviates, an error arises. If the correction requires significant energy (e.g., prolonged postural retraining, high metabolic expenditure), the system instead 'fixes' the error by embedding it into its baseline state, manifesting as subluxation.

The cost function can be expressed as:

$$F = \sum_i (p_i - \hat{p}_i)^2 \cdot w_i$$

where w_i represents the energy weighting of correcting vs. stabilising the error. Subluxation occurs when:

$$\Delta E_{correction} > \Delta S_{stability}$$

That is, the energy required to correct is greater than the cost of maintaining a stable but erroneous state.

This mechanism explains why subluxations persist despite apparent biomechanical inefficiency: (49) the system perceives the maladaptive attractor as less costly than continuous correction.

3. Application of Dynamical Systems Theory

Dynamical Systems Theory (DST) frames the organism as a nonlinear system with multiple attractor states. Subsystems such as posture, movement, and neural activity self-organise into relatively stable configurations. These attractors represent valleys in the system's energy landscape.

Subluxation, within this model, is an attractor basin. (7 - 9, 50) Once a vertebral segment or spinal region falls into a maladaptive configuration, it remains stable because the attractor basin is deep enough to resist perturbations. (51) Even external interventions may fail to dislodge the system if the attractor is sufficiently entrenched.

This dynamic can be described with a simple energy landscape equation:

$$\frac{dx}{dt} = -\nabla V(x)$$

where *V(x)* is the potential landscape, and *x* represents spinal configurations. Subluxation corresponds to a local minimum in *V(x)*.

The chiropractic adjustment can be understood as an external perturbation:

$$x(t+1) = x(t) + \Delta x_{adjustment}$$

which may elevate the system out of the attractor basin, enabling a transition to a new, potentially more adaptive state.

> Thus, subluxation is not merely a static lesion but a dynamical attractor, and adjustment is a perturbation capable of reshaping the energy landscape.

4. Application of Evolutionary Biology

From an evolutionary perspective, all organisms adopt strategies to minimise energy expenditure while maximising survival. Energy conservation is a driving force of phenotypic expression. Behaviours, postures, and structural adaptations must be understood in this context.

Subluxation, in this light, represents an evolutionary phenotype of energy-saving mechanisms (10 - 13, 52, 53) While appearing maladaptive at the level of spinal biomechanics, subluxation may reduce the organism's overall metabolic burden by stabilising prediction errors and reducing the need for constant correction.

For example, an individual with repetitive strain may adopt a spinal alignment that limits motion but requires less continuous neural computation for balance. The result is reduced short-term energy expenditure, even at the cost of long-term dysfunction.

Thus, subluxation can be framed as a trade-off:

$$Fitness = Survival_{short-term} - Cost_{long-term}$$

where subluxation increases short-term survival efficiency by lowering energy costs but may compromise long-term adaptability. (34)

5. Integrative Model of Subluxation

When the four frameworks are combined, a coherent model emerges:

1. Constructal Law: Subluxation = bottleneck in systemic flow optimising under constraints.

2. Free Energy Principle: Subluxation = fixation of prediction error due to cost-benefit imbalance. Subluxation, in this light, represents an evolutionary phenotype of energy-saving mechanisms (10 - 13, 52, 53) While appearing maladaptive at the level of spinal biomechanics, subluxation may reduce the organism's overall metabolic burden by stabilising prediction errors and reducing the need for constant correction.
3. Dynamical Systems Theory: Subluxation = attractor basin within an energy landscape.
4. Evolutionary Biology: Subluxation = phenotype of energy conservation across adaptive trade-offs.

6. Mathematical Integration

The combined model can be formalised as follows:

Total Energy Equation

$$E_{total}(t) = E_{flow}(t) + E_{prediction}(t) + E_{stability}(t)$$

where:

- E_{flow} = energy associated with physical flow resistance (Constructal Law)
- $E_{prediction}$ = energy cost of unresolved prediction errors (FEP)
- $E_{stability}$ = energy associated with remaining in a given attractor (DST)

Subluxation corresponds to:

$$\frac{\partial E_{total}}{\partial t} \to \min \quad \text{subject to constraints of } \Delta E_{correction} > \Delta S_{stability}$$

That is, subluxation is the emergent state that minimises total energy while locking the organism into a maladaptive but stable attractor.

Adjustment as Perturbation

Chiropractic adjustment is represented as an external perturbation:

$$E_{perturbation} > Depth(V_{subluxation})$$

meaning the adjustment must exceed the energy depth of the attractor basin to initiate a state transition.

7. Clinical Implications

This integrated model provides new insights into the persistence and correction of subluxations:

- Persistence: Subluxations persist because they are energetically stable states, not merely mechanical dysfunctions (32, 37)
- Adjustment Mechanism: Adjustments act as energetic perturbations that enable transitions to new attractors (50, 51)

- Variability of Response: Some subluxations resist correction because the energetic depth of their attractor basin is greater than the perturbation delivered (48)
- Research Pathways: The model generates testable hypotheses, such as measuring metabolic cost reductions post-adjustment or using neuro-imaging to track prediction error minimisation (53 - 55)

8. Summary of Results

The results of this theoretical integration demonstrate that vertebral subluxation can be reconceptualised as an emergent, energy-conserving phenomenon. Constructal Law, Free Energy Principle, Dynamical Systems Theory, and evolutionary biology converge on the insight that subluxation is not merely dysfunction but a systemic adaptation. Chiropractic adjustment, in turn, is not merely mechanical correction but a perturbation within the organism's energy landscape.

> This new model situates Chiropractic theory firmly within contemporary scientific discourse, offering both explanatory depth and clinical relevance.

Discussion

1. Reframing Vertebral Subluxation in Contemporary Science

For more than a century, vertebral subluxation has been a conceptual and philosophical pivot in Chiropractic, oscillating between metaphysical speculation and biomechanical reductionism (1 - 5) The integrative framework presented here repositions subluxation as an emergent, energy-conserving adaptive state embedded within universal principles governing living systems.

This shift from a static mechanical lesion toward a dynamic systems-based construct aligns Chiropractic theory with established scientific paradigms, including thermodynamics, cybernetics, and predictive coding. (6 - 9) By integrating the Constructal Law, Free Energy Principle (FEP), Dynamical Systems Theory (DST), and Evolutionary Biology, vertebral subluxation is reframed as a manifestation of the body's inherent drive to minimise energy expenditure and informational uncertainty. (10 - 14) In this model, subluxation emerges not as an error to be eliminated, but as a functional compromise, a locally stable attractor that balances structural constraints, predictive demands, and metabolic costs. (15 - 18)

This conceptual reframing also addresses longstanding criticisms that Chiropractic's central concept is outdated or unscientific. (19, 20) The integration with contemporary frameworks demonstrates that subluxation is consistent with universal biological tendencies:

- systems evolve toward optimised flow structures (Constructal Law) (21)
- organisms minimise surprise and prediction error (FEP) (22, 23, 24)
- adaptive states stabilise through attractor dynamics (DST) (25, 26, 27), and
- energy conservation governs phenotypic expression (Evolutionary Biology) (28 - 31)

Therefore, what was once viewed as a metaphysical abstraction may now be understood as a predictable systemic outcome of self-organising, energy-conserving processes across biological hierarchies.

2. Framework-Specific Implications

(a) Constructal Law: Flow Optimisation and Structural Constraints

According to Bejan's Constructal Law, all flow systems, ranging from river basins to neuronal networks, evolve to facilitate access to currents under constraints [21,32]. Within this paradigm, spinal architecture and alignment are not fixed mechanical entities but dynamic flow conduits for mechanical, neural, and vascular energy. (33, 34)

A vertebral subluxation, therefore, may represent a flow bottleneck that paradoxically enhances systemic efficiency by stabilising energy distribution within a constrained configuration. (35, 36) For example, chronic spinal asymmetries may reduce muscular energy demand by redistributing tension fields, an observation supported by electromyographic and postural adaptation studies. (37, 38)

Critics have often argued that such flow-based explanations are metaphoric rather than mechanistic. (39) However, the Constructal Law is a formally derived thermodynamic principle, not a metaphor. (21) When applied to the human spine, it provides a mathematical rationale for why certain 'malalignments' persist, they represent locally optimised flow architectures under evolutionary and biomechanical constraints.

b) Free Energy Principle: Prediction Error Fixation

The FEP posits that living systems maintain order by minimising variational free energy, an information-theoretic measure of prediction error between expected and sensed states. (22, 23, 24) The nervous system continuously updates its internal model to reduce surprise; yet when correction becomes energetically costly, the system may instead stabilise prediction errors, embedding them into its default state. (40 - 43)

In this context, vertebral subluxation corresponds to a fixed attractor of unresolved prediction error. Repeated postural strain, stress, or trauma generates discrepancies between predicted proprioceptive input ($\hat{p}i$) and actual sensory feedback (pi). (44) If $\Delta E_{correction} > \Delta S_{stability}$, correction is inhibited, and the subluxated configuration becomes a stable reference for further predictions. (45)

This mechanistic interpretation directly rebuts critiques that Chiropractic lacks a neuroscientific substrate (46, 47) It situates subluxation within the same predictive coding architecture that explains phenomena such as chronic pain, sensorimotor adaptation, and motor learning. (48 - 50) Thus, the FEP not only provides a bridge between Chiropractic and systems neuroscience but also offers quantifiable metrics, such as error minimisation rates and metabolic costs, for empirical testing. (51)

(c) Dynamical Systems Theory: Subluxation as an Attractor State

DST views biological systems as nonlinear dynamical entities with multiple stable attractor states. (25, 26, 27) Postural control, spinal coordination, and autonomic regulation are governed by such dynamics. (52) Within this framework, subluxation represents an attractor basin, a configuration that maintains stability despite external perturbations. (53)

Clinical observations often show that some subluxations resist correction or recur after adjustment. DST predicts this phenomenon: the depth of an attractor basin determines resistance to change. (54) Chiropractic adjustment acts as a perturbation, if the energy of the perturbation ($E_{perturbation}$) exceeds the basin depth ($V_{subluxation}$), the system transitions to a new, potentially more adaptive state. (55)

This model reconciles the variability in patient outcomes that has historically puzzled researchers. (56) It also implies that effective adjustments are not purely mechanical but energetic perturbations within a nonlinear control system, consistent with empirical studies showing changes in autonomic balance and cortical activity post-adjustment. (57, 58) *(d) Evolutionary Biology: Subluxation as Energy-Conserving Phenotype*

From an evolutionary perspective, all physiological adaptations are constrained by the imperative to conserve energy while maintaining survival and reproductive fitness. (28 - 31, 59) Misalignment, therefore, may not always indicate dysfunction; it can represent an adaptive trade-off that reduces immediate metabolic expenditure while sacrificing long-term flexibility. (60, 61, 62)

> This reasoning rebuts the claim that subluxation must be pathological by definition. (63) Instead, it can be conceptualised as a phenotypic expression of the organism's strategy to manage energy resources and prediction accuracy under ecological constraints.

Evolutionary models of posture and locomotion further support this view. Persistent spinal asymmetries, such as mild scoliosis or habitual tilting, can stabilise gaze control and balance with minimal energy cost. (64) These states, while suboptimal from a biomechanical standpoint, are energy-efficient attractors that the organism maintains unless perturbed.

3. Addressing Common Criticisms

The proposed model inevitably encounters skepticism from within and outside chiropractic. Yet most critiques arise from misunderstanding or from evaluating subluxation within outdated mechanical paradigms.

(a) "Subluxation is obsolete"

This criticism typically stems from equating subluxation with a literal bone misalignment compressing nerves. (19, 63) The present framework transcends such reductionism. Subluxation is redefined as an emergent information–energy state, analogous to attractor states in neural networks or metastable configurations in complex systems. (25, 40, 53)

By situating the concept within universal physical and biological laws, obsolescence is rendered irrelevant, it becomes a matter of scale and interpretation rather than existence.

(b) "There is no empirical evidence for subluxation"

Empirical data supporting subluxation depends on its definition. If defined narrowly as mechanical dislocation, evidence is limited; but when defined as a functional energy and information imbalance, substantial indirect support exists. (47, 48, 57, 58) Studies demonstrate measurable neurophysiological and metabolic changes following spinal manipulation. (65, 66)

The proposed framework generates testable hypotheses, for instance, measuring reduction in neural prediction error via fMRI or EEG pre- and post-adjustment. (51, 67)

(c) "Energy conservation is metaphorical"

Energy is not a metaphor but a quantifiable biophysical variable. The Constructal Law, FEP, and DST are all mathematically formalised theories rooted in thermodynamics and information theory. (21 - 27) Applying them to Chiropractic phenomena is conceptually identical to applying them to cardiac physiology or neural computation. Hence, the energy-based interpretation enhances, rather than dilutes, scientific rigour. (46, 68) *(d) "Evolutionary reasoning is speculative"*

Evolutionary framing explains why certain maladaptive patterns persist. The principle of least action applies not only to physical systems but to biological evolution itself. (59, 69)

Subluxation's persistence, despite inefficiency, reflects the energy–stability trade-off that pervades evolution. This reasoning parallels established models in evolutionary medicine explaining obesity, chronic inflammation, and allostasis. (70, 71, 72)

(e) "Adjustments are placebo responses"

While expectation and contextual factors contribute to outcomes, numerous studies show physiological effects of spinal adjustment, altered somatosensory processing, improved motor output, and autonomic modulation. (57, 65, 66) The current model explains these effects mechanistically: adjustments function as controlled energetic perturbations, not mere placebo stimuli.

4. Clinical and Educational Implications

Clinically, this model redefines the Chiropractor's role. The practitioner no longer merely 'realigns' vertebrae but modulates systemic energy flowand prediction dynamics. Adjustments act as targeted perturbations designed to restore flexibility in the organism's energy landscape. (55, 57)

Patient communication can likewise evolve. Instead of invoking metaphysical 'Innate Intelligence'" clinicians can describe subluxation as a neuro-energetic adaptation that has become maladaptive. Such language maintains Chiropractic's identity while aligning with contemporary neuroscience. (47, 48)

Educationally, this framework urges a curricular shift. Chiropractic students should study principles of thermodynamics, complex systems, and computational neuroscience alongside anatomy and technique. Integrating these sciences provides the epistemic foundation to articulate subluxation in a language intelligible to the broader scientific community. (73, 74, 75)

5. Research Agenda and Empirical Pathways

The integrative model offers a robust roadmap for future empirical investigation:

1. Neuro-imaging Studies: Use fMRI or EEG to quantify changes in prediction error or neural entropy post-adjustment. [51,67].
2. Metabolic Cost Analysis: Employ indirect calorimetry to measure energy efficiency in postural tasks before and after Chiropractic care. (76, 77)
3. Nonlinear Dynamics: Apply recurrence quantification analysis (RQA) and attractor reconstruction to spinal motion data (78, 79)
4. Comparative Evolutionary Research: Investigate subluxation-like adaptations in energy-limited animal models. (80, 81)
5. Computational Simulations: Model subluxation formation using FEP-informed generative networks to predict attractor formation and correction thresholds. (82)

These research pathways can empirically validate, or refine, the theoretical synthesis presented here, transforming chiropractic from a conceptual tradition into a quantitative systems science.

6. Limitations and Future Directions

This framework, though comprehensive, remains primarily theoretical. Operationalising constructs like 'attractor depth' or 'prediction error fixation' will require methodological innovation.

Collaboration with physicists, neuroscientists, and evolutionary theorists is essential to translate these abstractions into measurable phenomena. (83, 84)

Moreover, while the model unifies Chiropractic theory, it may not capture the full complexity of clinical variability influenced by psychosocial and contextual factors. Future research should integrate biopsychosocial dynamics with biophysical mechanisms for a holistic systems model. (85)

7. Conclusion of Discussion

Reconceptualising vertebral subluxation as an emergent, energy-conserving attractor state provides Chiropractic with renewed scientific legitimacy and theoretical coherence. By embedding subluxation within the principles of flow optimisation (Constructal Law), prediction error minimisation (FEP), dynamical stability (DST), and evolutionary energy conservation, this framework demonstrates that the phenomenon is neither metaphysical nor obsolete but biologically inevitable.

Skepticism toward subluxation arises primarily from outdated mechanistic definitions. When reinterpreted through these modern scientific lenses, Chiropractic's central concept becomes a fertile domain for interdisciplinary research linking physics, neuroscience, and evolutionary theory.

In this light, Chiropractic adjustment is redefined as a strategic perturbation, a deliberate modulation of the organism's energy landscape designed to restore adaptive flexibility, optimise systemic efficiency, and recalibrate predictive models.

Thus, rather than a relic of 19th Century vitalism, vertebral subluxation emerges as a 21st Century systems phenomenon, a dynamic interface between structure, function, and energy flow within living systems.

Conclusion

This manuscript has argued that vertebral subluxation, far from being an obsolete or purely philosophical construct, can be rigorously reframed as an emergent energy-conserving state arising from the interplay of universal principles governing living systems. By integrating insights from the Constructal Law, the Free Energy Principle, Dynamical Systems Theory, and evolutionary biology, we have articulated a functional-first model of subluxation. This model explains its persistence, variability, and clinical relevance in a manner consistent with contemporary science.

The significance of this reframing is twofold. First, it provides Chiropractic with a scientific anchor for its central concept. For over 130 years, Chiropractic's identity has revolved around subluxation, yet its definitions have been fragmented, contested, and often reduced to individual belief. By grounding subluxation in established scientific laws, Chiropractic gains conceptual clarity and legitimacy. Second, the integrative model shifts the debate away from outdated dichotomies, whether subluxation is 'real' or 'illusory', toward a more productive question:

> How does subluxation function as a systemic adaptive mechanism, and how can Chiropractic care optimise its modulation?

This new theoretical synthesis yields several practical implications. Clinically, subluxation should no longer be regarded as a mere spinal fault or mechanical misalignment. Instead, it represents a trade-off strategy: an attractor state in the organism's energy landscape that stabilises prediction error, simplifies flow architecture, and reduces immediate metabolic costs at the expense of long-term adaptability.

Chiropractic adjustment, correspondingly, is not merely the restoration of vertebral alignment but a designed perturbation intended to shift the system toward more flexible, energy-efficient states.

Educationally, this model demands that Chiropractic curricula incorporate principles from physics, systems neuroscience, and evolutionary biology. Such interdisciplinary foundations not only deepen the theoretical understanding of subluxation but also situate Chiropractic as a participant in broader scientific conversations.

For students and practitioners alike, this reframing elevates chiropractic from insular debates to cross-disciplinary integration. From a research perspective, the model provides a fertile landscape for testable hypotheses.

Adjustments should be studied not only for their biomechanical effects but also for their impact on prediction error minimisation (via neuro-imaging), metabolic efficiency (via calorimetry), and attractor dynamics (via nonlinear time series analysis). This agenda opens pathways for collaborations between Chiropractors and computational neuroscientists, physiologists, and evolutionary theorists.

At the same time, we must acknowledge limitations. The current framework is theoretical and relies heavily on analogies across scientific domains. Operationalising concepts such as 'attractor basin depth' or 'prediction error fixation' remains a methodological challenge.

Future research must bridge these abstractions with measurable clinical outcomes. Nevertheless, the history of science is replete with concepts that began as theoretical integrations and only later acquired empirical specificity.

Ultimately, the reframing of vertebral subluxation as a phenotypic expression of energy conservation provides Chiropractic with both continuity and renewal. Continuity, because it preserves subluxation as the profession's central concept. Renewal, because it transcends outdated definitions and situates chiropractic within the most advanced explanatory frameworks available.

This integration aligns Chiropractic's unique contribution with universal scientific principles, ensuring its relevance for both clinical practice and future scholarship.

In conclusion, vertebral subluxation should be understood not as a chaotic or outdated construct, but as a predictable, emergent state arising from the universal drive of living systems to conserve energy and maintain stability. Chiropractic adjustment should be understood not merely as structural correction, but as a strategic perturbation within the organism's energy landscape, a deliberate intervention that restores adaptive flexibility, updates predictive models, and optimises systemic function.

This reconceptualisation not only secures the philosophical and clinical foundation of Chiropractic but also opens a new frontier of interdisciplinary research. Subluxation is not simply a problem to be solved, but a window into the deep principles of life itself.

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