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Hypothesis

From Vasomotion to Interoception: The PULSE-V Hypothesis of Predictive Tissue Regulation in Manual Medicine

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Abstract

Manual medicine has long outgrown explanations resting solely on structural-biomechanical correction. While the techniques reliably alleviate musculoskeletal pain and functional complaints, durable benefit appears to depend far less on lasting mechanical realignment than on a distributed set of neurophysiological, autonomic, interoceptive, and contextual processes. A persistent translational gap nevertheless remains between abstract predictive models of bodily regulation and the tangible regional tissue dynamics that clinicians encounter in practice. We propose PULSE-V (Predictive Updating of Local Somatic Errors via Vasomotion) as a hypothesis-generating framework intended to narrow that gap. The central suggestion is that low-frequency vasomotor oscillations (~0.1 Hz) within angiosomes, when exhibiting optimal fractal complexity and multiscale organisation, may serve as a candidate biophysical substrate capable of structuring ascending interoceptive signals. When this complexity is disrupted—shifting microvascular dynamics towards either rigid periodicity or stochastic noise—the resulting afferent stream may become ambiguous and contribute to interoceptive prediction error. Chronic somatic dysfunction can then be understood as a maladaptive attractor state: a self-stabilising loop in which ambiguous peripheral input, impaired sensory attenuation, and entrenched top-down priors reinforce one another. PULSE-V is offered as a deliberately falsifiable program rather than a settled theory. It generates testable predictions concerning regional vasomotor patterns, multimodal biomarker signatures, and the differential contributions of vasomotor, affective-touch, and relational treatment elements. If supported, the model would offer a mechanistically grounded account of the frequently observed discrepancy between the modest mechanical effects of manual intervention and the substantial clinical outcomes that follow.

Keywords: active inference; interoception; allostasis; vasomotion; angiosomes; manual therapy

1. Introduction/Background

Manual therapy and osteopathic manipulative treatment continue to occupy a central place in the management of musculoskeletal pain and functional disorders [1,2]. For much of the twentieth century, the prevailing explanatory framework was straightforward: practitioners identify a mechanical fault — restricted joint mobility, positional asymmetry, altered tissue texture — and apply a corrective force to restore normal alignment or movement [3]. This structural-biomechanical account was intuitively appealing and closely aligned with clinical experience.

Over recent decades, however, that narrative has become increasingly difficult to defend. Inter-rater reliability for the palpatory detection of discrete structural abnormalities remains modest [4]. Objective evidence of sustained positional change following intervention is sparse [5]. Clinical outcomes show surprisingly weak correlation with the mechanical variables that were ostensibly

addressed [6]. Concurrently, manual interventions are known to engage descending nociceptive modulation, autonomic tone shifts [7], affective-touch pathways [8], expectation effects [9], and the quality of the therapeutic relationship [10]. The conventional distinction between “specific” biomechanical actions and “non-specific” contextual influences has therefore lost much of its explanatory utility [11].

In parallel, neuroscience has moved decisively towards predictive accounts of perception and bodily regulation [12,13]. Allostatic regulation in physiology and active inference in computational neuroscience converge in describing the brain as an anticipatory system that generates internal models of bodily state and updates them by minimising prediction error. Interoception, within this paradigm, is an active inferential process in which descending expectations are continually tested against ascending evidence [1,13]. Applied to persistent pain and somatic dysfunction, this perspective suggests that bodily distress arises not only from local tissue events but also from maladaptive inferential dynamics, in which poorly structured peripheral input fails to dislodge entrenched, threat-oriented priors [14,15].

This conceptual shift creates a clear translational challenge. Predictive frameworks are elegant at the computational level yet remain abstract when one tries to relate them to the regional tissue phenomena that clinicians palpate daily [2,4]. Manual practitioners work with changes in tissue texture, vascularity, resistance, tenderness, and dynamic compliance; predictive neuroscience speaks of precision weighting, generative models, and free-energy minimisation [12,13]. The vascular system offers a particularly promising point of contact [16]: manual techniques consistently produce measurable alterations in peripheral perfusion and autonomic balance [7,17], yet no widely accepted model explains how these local events might shape central interoceptive inference [1,18]. The hypothesis set out below addresses precisely that question.

2. The Hypothesis

PULSE-V rests on a central premise — that regional vascular-tissue dynamics may constitute the missing physiological link between manual medicine and predictive neuroscience [2,11] — operationalised through three components. The model proposes that angiosomes may serve as plausible peripheral units of functional regulation [19,20]; that the microcirculatory-tissue system may operate as a distributed sensorimotor interface [21]; and that vasomotor oscillations exhibiting optimal multiscale complexity may provide a candidate biophysical substrate for organising ascending interoceptive signals [22].

2.1. Angiosome as a Unit of Regional Predictive Regulation

Originally developed in reconstructive surgery, an angiosome describes a three-dimensional tissue territory supplied by a single source artery and characterised by its local vascular architecture [23]. We reconceptualise the angiosome as a regional physiological domain in which multiple tissue layers share a common haemodynamic resource and, potentially, a coordinated oscillatory state [16,19]. These tissues are coupled through microvascular supply, metabolic demand, and vasomotor interaction. We therefore propose that the angiosome functions as an anatomically coherent unit for local predictive regulation, in which shared haemodynamic drive, coordinated sympathetic vasomotor tone, and metabolically coupled thin-fibre afferent signalling converge [24,25].

2.2. Microcirculatory Tissue System as a Distributed Transduction Interface

Within this domain, the microcirculatory-tissue system functions as far more than a passive conduit for blood [25,26]. Vessel walls, perivascular tissues, stromal elements, connective matrices, and metabolically sensitive group III/IV afferents — responsive to mechanical strain, local pH, pO₂, and ischaemic metabolites — together constitute a distributed transduction interface [26]. The state of the tissue is, therefore, not represented by a static parameter such as pressure or flow rate, but by a dynamically organised vascular-tissue pattern [24].

2.3. Vasomotion as a Candidate Biophysical Substrate

The principal candidate signal within this pattern is vasomotion — the spontaneous low-frequency oscillation of microvascular tone [25,27]. We do not contend that vasomotion exclusively encodes interoceptive information. Rather, we propose that vasomotor oscillations operating within an optimal range of fractal complexity — characterised by $1/f$ dynamics and high multiscale entropy [27,28] — may help structure ascending afferent input, conferring temporal organisation, salience, and functional precision on signals generated within vascularised tissue [18,22]. This state of optimal complexity is distinct from rigid bilateral synchrony, which may reflect top-down sympathetic override, and from stochastic variability, which lacks informational structure [24,29]. When microvascular complexity is lost — through maladaptive flow redistribution, chronic ischaemia, or excessive centralised sympathetic drive — the afferent stream becomes ambiguous and noisy [15,29].

Optimal microvascular complexity is therefore advanced as a candidate biophysical basis for informative regional bodily signalling [28,30]. A loss of this complexity — presenting as reduced fractal scaling, diminished multiscale entropy, or imposition of rigid centralised rhythmicity — constitutes a possible peripheral physiological correlate of interoceptive prediction error [15,30]. Under such conditions, ambiguous peripheral evidence fails to prompt meaningful updating of central models [13].

3. Evaluation of the Hypothesis

The mechanistic rationale of PULSE-V can be traced as a reciprocal cascade linking regional vascular dynamics to central interoceptive regulation [1,2]. Rather than supposing that the brain receives a direct isomorphic representation of tissue state, we suggest that peripheral vascular organisation fundamentally shapes how bodily information is filtered, weighted, and integrated across multiple physiological levels [11,13].

3.1. Local Origin and Afferent Transduction

Within a given angiosomal territory, chronic mechanical stress, persistent postural loading, microischaemia, or unresolved inflammation can disrupt the natural variability of microvascular oscillations [21]. This does not necessarily entail overt vascular failure; it entails a shift away from the optimal fractal complexity that characterises healthy nonlinear physiology [30], towards either rigid, low-entropy periodicity or disorganised stochastic variability — both of which yield less informative microcirculatory dynamics [31]. Polymodal and thin-fibre afferents transduce this disrupted local environment, generating a fragmented and temporally irregular ascending stream [32].

The specific mechanism by which afferents detect fractal properties of vasomotion — whether through frequency entrainment of discharge patterns to vasomotor cycles, oscillation-dependent metabolite fluctuations (lactate, H^+ , adenosine) that modulate group IV firing, or mechanosensitive detection of rhythmic vessel-wall strain by perivascular endings — remains to be established empirically and constitutes one of the most important tests of the present framework.

3.2. Ascending Integration and Inferential Mismatch

These signals ascend via lamina I spinal pathways, the lateral parabrachial nucleus, and thalamic relay nuclei to reach posterior insular representations [32]. At this level ascending evidence meets descending allostatic predictions [13,30]. In a well-regulated system precise peripheral signals continually refine cortical models. When the afferent stream is chronically noisy or assigned low precision — owing to a loss of optimal peripheral microvascular complexity [18,30] — it may fail to dislodge maladaptive priors [14,15]. The system then defaults to established expectations of threat, pain, or functional deficit, actively attenuating or discounting ambiguous peripheral data [33].

3.3. Self-Sustaining Attractor

This inferential mismatch tends to become self-sustaining. To minimise prediction error, the nervous system generates compensatory efferent outputs — regional vasoconstrictive bias, protective muscle activation, altered tissue loading [30,34]. These responses further compromise local perfusion, perpetuating the loss of optimal microvascular complexity [27,29] and progressively stabilising a maladaptive attractor state [15,30]. Chronic somatic dysfunction thus arises not solely from peripheral tissue events, nor exclusively from aberrant cortical prediction, but from a progressive failure of reciprocal regulation across scales [28].

3.4. Consistency with Published Evidence

The hypothesis is consistent with a substantial body of published evidence. Network-physiology studies demonstrate hierarchical coupling among physiological subsystems with health-related complexity signatures [28]. Vasomotion research shows that microvascular oscillation patterns are altered in diabetes and hypertension, with reduced complexity tracking disease severity [27,29]. Predictive-coding accounts of chronic pain explicitly invoke imbalances between ascending precision and descending priors as a generative mechanism [14,15]. Manual-medicine studies have documented autonomic, interoceptive, and insular changes following osteopathic intervention [17]. Conversely, two key claims of PULSE-V — angiosome-specific interoceptive coding and bilateral vasomotor synchrony as a marker of central override — currently rest on indirect evidence and remain important targets for falsification (see Section 6.3).

4. Hypothesis Testing

The principal merit of PULSE-V lies in its falsifiability. The model generates several predictions that can, in principle, be refuted.

4.1. Predictions at the Peripheral Level

Microcirculatory oscillations should exhibit significantly greater intra-territorial fractal complexity — indexed by higher multiscale entropy [35,36] and $1/f$ scaling [28,30] — within functionally linked angiosomal territories than across adjacent but haemodynamically distinct regions [29,37]. Clinically effective manual interventions should be associated with measurable improvements in regional microvascular complexity (multiscale entropy, fractal scaling) [27,38], in at least a substantial proportion of cases. Bilateral vasomotor synchrony, by contrast, is expected to decrease following effective intervention [17], reflecting release from centralised sympathetic override rather than loss of physiological organisation [24].

4.2. Cross-Scale Predictions

These peripheral changes should not remain isolated. If the hypothesis holds, improvements in regional microvascular complexity should correlate specifically with measures of interoceptive accuracy — such as the heart rate discrimination task or comparable proxy measures — and with autonomic indices of precision regulation [2], rather than aligning solely with subjective symptom reports [37,39,40]. Distinct therapeutic signatures may also emerge depending on whether the intervention primarily engages vasomotor, affective-touch, or contextual channels [8,10,26].

4.3. Methodological Approach

Empirical evaluation requires a multimodal approach [24]. Established peripheral tools include laser Doppler flowmetry, photoplethysmography [41], near-infrared spectroscopy [42], and heart-rate variability analysis [7]. Bilateral laser Doppler flowmetry permits assessment of Mayer-wave (~ 0.1 Hz) coherence between symmetric angiosomal territories as a candidate index of centralised sympathetic override. Where feasible, these can be combined with neuroimaging sensitive to insular and salience-network dynamics [1,39]. Quantitative analysis should rely on validated nonlinear measures (multiscale entropy, detrended fluctuation analysis, spectral entropy rates) rather than

first-order summary statistics [35–38]. Because the model spans multiple physiological scales, a convincing positive result would demonstrate coordinated shifts across peripheral, autonomic, and central domains [28].

4.4. Falsification Criteria

PULSE-V would be falsified if (i) regional vascular dynamics showed no reproducible relationship with validated interoceptive proxies (e.g., heart rate discrimination task accuracy or MAIA-2 interoceptive awareness scores) [43,44] across at least two independent cohorts; (ii) clinically meaningful improvement, defined as change exceeding the established MCID for the primary outcome, occurred in $\geq 50\%$ of responders without concurrent changes in regional vasomotor organisation exceeding the test–retest variability of bilateral laser Doppler flowmetry indices (Mayer-wave coherence, multiscale entropy, or DFA α_1) [45,46], replicated across at least two independent cohorts; or (iii) angiosome-defined territories failed to display greater intra-territorial coherence in vasomotor complexity than haemodynamically unrelated control regions across at least two independent cohorts [16].

5. Empirical Data

No new empirical data or pilot data are presented in this article. PULSE-V is advanced as a synthesis of previously published research and is offered for subsequent experimental testing.

6. Consequences of the Hypothesis and Discussion

6.1. Three Concurrent Therapeutic Channels

Should PULSE-V prove broadly correct, manual intervention would modulate chronic dysfunction through the interplay of multiple overlapping channels [2].

The first is vasomotor. Mechanical loading, fascial decompression, rhythmic stretching, and shear stress can alter local haemodynamics [47] and may help restore optimal fractal complexity in regional vascular oscillations [48]. In predictive terms, this reduces ambiguity in the peripheral signal, increasing the probability that ascending input contributes to updating higher-order cortical predictions [13,18]. This channel may be particularly relevant when tissues are congested or dynamically restricted — presentations in which vascular-tissue dysregulation may play a substantial role alongside any purely mechanical component [7].

The second is C-tactile. Slow, affective touch engages CT afferents that project via lamina I and the thalamus to posterior insular networks [32]. CT-mediated input is closely associated with safety signalling and autonomic downregulation [8]. This stream can compete with threat-related signals and may assist in recalibrating the salience of bodily information [11,15]. Clinical and experimental evidence suggests that effectiveness often depends less on the intensity of mechanical force than on the quality of contact — one that is frequently affective and relational [10].

The third is interpersonal and contextual. The therapeutic alliance, patient expectation, and the perceived meaning of the encounter act as powerful top-down modulators of precision weighting [10]. Contextual factors do not merely accompany the technique; they actively alter which sensory signals are amplified and which are attenuated [11,49]. This helps account for the substantial variability in outcome when apparently similar manual methods are applied by different practitioners or in different relational settings [4].

These channels are not mutually exclusive; they operate concurrently and in synergy [30]. Their relative dominance varies according to the patient, the tissue involved, and the chronicity of the complaint [34]. PULSE-V, therefore, offers a flexible conceptual structure for understanding why manual interventions that appear technically comparable can produce markedly different clinical results [50].

6.2. Implications

If confirmed, PULSE-V provides a mechanistically grounded account of the frequently observed discrepancy between modest mechanical effects and substantial clinical outcomes. It reframes manual intervention as a targeted perturbation of a dysregulated multi-level system rather than as simple mechanical correction [4,28]. It also offers a concrete bridge between predictive neuroscience and clinical palpation, suggesting that what skilled clinicians perceive as “tissue quality” may correspond to multiscale dynamical organisation rather than to static mechanical properties.

6.3. Limitations

We must acknowledge the boundaries of the present framework. PULSE-V is an interpretive hypothesis rather than a fully validated physiological theory, and two specific claims warrant explicit caution. First, the interpretation of bilateral vasomotor synchrony as a marker of centralised sympathetic override — rather than coordinated physiological response — currently rests only on indirect evidence from pathological populations [27,29]; direct experimental support in healthy participants using bilateral laser Doppler flowmetry remains lacking.

Second, direct empirical evidence for angiosome-specific interoceptive coding is sparse [19], and the question of how boundaries between adjacent angiosomal territories — including regions of inter-territorial vascular anastomosis — may relate to interoceptive regionalisation awaits systematic investigation. There is also a persistent risk of overextending computational concepts onto biological tissue in the absence of adequate empirical support [12].

We have deliberately circumscribed the model to maintain a clear focus on vascular dynamics. As a consequence, it does not yet fully incorporate the substantial contributions of humoral, glial, endocrine, immune, and microbiome factors to chronic dysfunction, nor does it provide a formal computational implementation with quantified parameters [14]. The clinical implications discussed here are therefore hypothesis-guided rather than prescriptive; their primary purpose is to stimulate experimentally tractable questions rather than to dictate clinical practice.

6.4. Conclusion

PULSE-V offers a translational hypothesis that connects angiosomal tissue organisation, microcirculatory dynamics, and active interoceptive inference within a single framework. It suggests that microvascular dynamics operating at optimal fractal complexity may help organise ascending bodily signals, while a loss of that complexity — whether towards rigid centralised synchrony or stochastic noise — may contribute to maladaptive interoceptive inference in chronic somatic dysfunction. By reframing manual intervention as a multilevel perturbation of predictive tissue regulation rather than simple mechanical correction, the model provides a testable basis for further investigation in manual medicine, interoception research, and regional neurovascular physiology.

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