Hypothesis

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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 that rest solely on structural-biomechanical correction. While the techniques reliably alleviate musculoskeletal pain and functional complaints, the evidence suggests that durable benefit depends 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 these 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 that seeks 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 programme 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 elements in treatment. If supported, the model offers 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; osteopathy

1. Introduction: From Biomechanical Correction to Predictive Regulation

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

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outcomes show surprisingly weak correlation with the mechanical variables that were ostensibly addressed [6]. Concurrently, a growing body of clinical and experimental studies indicates that manual interventions engage a wide array of distributed mechanisms: descending nociceptive modulation [7], autonomic tone shifts [8], affective touch pathways [9], expectation effects [10], and the quality of the therapeutic relationship [11]. The conventional distinction between "specific" biomechanical actions and "non-specific" contextual influences has therefore lost much of its explanatory utility [12].

In parallel, neuroscience has moved decisively towards predictive accounts of perception and bodily regulation [13,14]. Converging perspectives — allostatic regulation in physiology and active inference in computational neuroscience — describe 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 not the passive reception of visceral signals but an active inferential process in which descending expectations are continually tested against ascending evidence [2,13]. 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 — situations in which poorly structured or noisy peripheral input fails to dislodge entrenched, threat-oriented priors [15,16].

This conceptual shift creates a clear translational challenge. Predictive frameworks are elegant at the computational level yet remain abstract when one attempts to relate them to the regional tissue phenomena that clinicians palpate daily [1,4]. 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 [13,14]. The two domains seldom connect in a concrete way.

The vascular system offers a particularly promising point of contact [17]. Manual techniques consistently produce measurable alterations in peripheral perfusion and autonomic balance [5,8,18], yet no widely accepted model explains how these local vascular-tissue events could influence central interoceptive inference [2,19,20]. The hypothesis set out below is an attempt to address precisely that question.

2. The Core Hypothesis of PULSE-V

PULSE-V rests on a central premise — that regional vascular-tissue dynamics may constitute the missing physiological link between manual medicine and predictive neuroscience [1,12] — operationalised through three components. Specifically, the model proposes that angiosomes may serve as plausible peripheral units of functional regulation [21,22], that the microcirculatory-tissue system may operate as a distributed sensorimotor interface [23], and that vasomotor oscillations exhibiting optimal multiscale complexity may provide a candidate biophysical substrate for organising ascending interoceptive signals [24].

The angiosome concept stands at the heart of this proposal [22]. 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 [17]. In the present framework 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 [17,22,25]. 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 — one in which shared haemodynamic drive, coordinated sympathetic vasomotor tone, and metabolically coupled thin-fibre afferent signalling converge [26,27].

Within this domain the microcirculatory-tissue system functions as far more than a passive conduit for blood [26,28]. Vessel walls, perivascular tissues, stromal elements, connective matrices, and metabolically sensitive group III/IV afferents — responsive to mechanical strain, local pH, pO_2, and ischaemic metabolites — together constitute a distributed transduction interface [28,29]. The state

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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 [25,27].

The principal candidate signal within this pattern is vasomotion — the spontaneous low-frequency oscillation of microvascular tone [17,26,30]. We do not contend that vasomotion exclusively encodes interoceptive information. We propose that vasomotor oscillations operating within an optimal range of fractal complexity — characterised by 1/f dynamics and high multiscale entropy [25,30] — may help structure ascending afferent input, conferring temporal organisation, salience, and functional precision on signals generated within vascularised tissue [19,24]. This state of optimal complexity is distinct from either rigid bilateral synchrony, which may reflect top-down sympathetic override, or stochastic variability, which lacks informational structure [27,31]. When microvascular complexity is lost — whether through maladaptive flow redistribution, chronic ischaemia, or excessive centralised sympathetic drive — the afferent stream becomes ambiguous and noisy [15,31].

Optimal microvascular complexity is therefore advanced as a candidate biophysical basis for informative regional bodily signalling [25,32]. A loss of this complexity — whether presenting as reduced fractal scaling, diminished multiscale entropy, or the imposition of rigid centralised rhythmicity — constitutes a possible peripheral physiological correlate of interoceptive prediction error [15,32]. Under such conditions, ambiguous peripheral evidence fails to prompt meaningful updating of central models [13,24].

3. Mechanistic Rationale: A Hierarchical Bridge from Tissue to Inference

The mechanistic rationale of PULSE-V can be traced as a reciprocal cascade linking regional vascular dynamics to central interoceptive regulation [2]. Rather than supposing that the brain receives a direct isomorphic representation of tissue state, we suggest that peripheral vascular organisation fundamentally shapes the way bodily information is filtered, weighted, and integrated across multiple physiological levels [12,13].

The sequence begins locally. Within a given angiosomal territory, chronic mechanical stress, persistent postural loading, microischaemia, or unresolved inflammation can disrupt the natural variability of microvascular oscillations [17,26]. This does not necessarily entail overt vascular failure; it entails a shift away from the optimal fractal complexity that characterises healthy nonlinear physiology [25,32] — towards either rigid, low-entropy periodicity or disorganised stochastic variability, both of which yield less informative microcirculatory dynamics [27,30,31]. That altered local environment immediately affects sensory transduction. Polymodal and thin-fibre afferents transduce this disrupted local environment, generating a fragmented and temporally irregular ascending stream [29]. These afferents are highly responsive to mechanical tension, temperature, chemical milieu, and ischaemic metabolites. The specific mechanism by which afferents detect fractal properties of vasomotion — whether through frequency entrainment of discharge patterns, oscillation-dependent metabolite fluctuations, or mechano-sensitive detection of rhythmic wall strain — remains to be established empirically — a gap that constitutes one of the most important empirical tests of the present framework. Tissue perturbation matters here not merely because it compromises perfusion, but because it compromises the informational quality of the evidence reaching higher regulatory centres [19,25].

These signals ascend via lamina I spinal pathways, the lateral parabrachial nucleus and thalamic relay nuclei to reach posterior insular representations [2,33]. This thin-fibre input contributes to cortical interoceptive mapping by providing the insula with a continuous, region-referenced signal of peripheral tissue state. At this level ascending evidence meets descending allostatic predictions [7,13]. 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 [19,32] — it may fail to dislodge maladaptive priors [15,16]. The system then defaults to established expectations of threat, pain, or functional deficit, actively attenuating or discounting ambiguous peripheral data [34,35].

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This inferential mismatch tends to become self-sustaining. In order to minimise prediction error, the nervous system generates compensatory efferent outputs — regional vasoconstrictive bias, protective muscle activation, altered tissue loading [5,8]. These responses further compromise local perfusion [30,31], perpetuating the loss of optimal microvascular complexity [25,32] and progressively stabilising a maladaptive attractor state [15,32]. 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 [25,36].

By situating manual medicine within this network-physiology perspective, PULSE-V casts clinical touch as a targeted perturbation capable of disrupting a dysregulated multi-level system [4,25].

4. Clinical Implications of the Hypothesis

Should PULSE-V prove broadly correct, manual intervention would modulate chronic dysfunction through the interplay of at least three partially overlapping channels [1,12].

The first is vasomotor. Mechanical loading, fascial decompression, rhythmic stretching, and shear stress can alter local haemodynamics [20,37] and may help restore optimal fractal complexity in regional vascular oscillations [30,32,38]. In predictive terms this reduces ambiguity in the peripheral signal, thereby increasing the probability that ascending input can contribute to updating higher-order cortical predictions [13,19]. This channel may be particularly relevant when tissues present as congested or dynamically restricted — presentations in which vascular-tissue dysregulation may play a substantial role alongside any purely mechanical component [5,8].

The second is C-tactile. Slow, affective touch engages CT afferents that project via lamina I and parabrachial relay nuclei to posterior insular networks. CT-mediated input is closely associated with safety signalling and autonomic downregulation [2,9]. This stream of input can compete with threat-related signals and may assist in recalibrating the salience of bodily information [12,15]. Clinical and experimental evidence suggests that the effectiveness of an intervention often depends less on the intensity of mechanical force than on the quality of contact — a quality that is frequently affective and relational [11].

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 [10,11]. Contextual factors do not merely accompany the technique; they actively alter which sensory signals are amplified and which are attenuated [12,39]. This helps to 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 [25,27]. Their relative dominance will vary according to the individual patient, the tissue involved, and the chronicity of the complaint. PULSE-V therefore offers a flexible conceptual structure for understanding why manual interventions that appear technically comparable can produce markedly different clinical results [1,4].

5. Testable Predictions and Methodological Approach

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

At the peripheral level, microcirculatory oscillations should exhibit significantly greater intra-territorial fractal complexity — indexed by higher multiscale entropy [40,41] and 1/f scaling [42] — within functionally linked angiosomal territories [17] than across adjacent but haemodynamically distinct regions [31,43]. Moreover, clinically effective manual interventions should be associated with measurable improvements in regional microvascular complexity — indexed by multiscale entropy and fractal scaling [25,30,44,45] — in at least a substantial proportion of cases. Bilateral vasomotor

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synchrony, by contrast, is expected to decrease following effective intervention [5,18], reflecting a release from centralised sympathetic override rather than a loss of physiological organisation [8,27].

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 heartbeat detection task or comparable proxy measures — and with autonomic indices of precision regulation, rather than aligning solely with subjective symptom reports [43,44,46,47]. Distinct therapeutic signatures may also emerge depending on whether the intervention primarily engages vasomotor, affective-touch, or contextual channels [9,11,28].

Empirical evaluation requires a multimodal approach [25,27]. Established tools include laser Doppler flowmetry, photoplethysmography [48], near-infrared spectroscopy, and heart rate variability analysis [8]. Where feasible, these can be combined with neuroimaging sensitive to insular and salience-network dynamics [2]. Because the model spans multiple physiological scales, a convincing result would demonstrate coordinated shifts across peripheral, autonomic, and central domains [5,25]. Conversely, the hypothesis would be falsified if regional vascular dynamics showed no reproducible relationship with interoceptive proxies across multiple independent cohorts, or if marked clinical improvement routinely occurred in the complete absence of any detectable change in vascular-tissue organisation [49].

6. Limitations

We must acknowledge the boundaries of the present framework [50]. PULSE-V is an interpretive hypothesis rather than a fully validated physiological theory. Several of its proposed links remain inferential [49]. In particular, the interpretation of bilateral vasomotor synchrony as a marker of centralised sympathetic override — rather than coordinated physiological response — is currently supported by indirect evidence from pathological populations [30,31]; direct experimental support in healthy participants using bilateral laser Doppler flowmetry remains lacking [51,52]. Direct empirical evidence for angiosome-specific interoceptive coding remains sparse [22], 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 without adequate empirical support [14].

We have deliberately circumscribed the model in scope in order 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 [25,36,53,54], nor does it provide a formal computational implementation with quantified parameters [16]. 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 [50].

7. 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 as simple mechanical correction, the model may provide a testable basis for further investigation in manual medicine, interoception research, and regional neurovascular physiology.

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