The Medical Science of Qigong and Neidan

氣功與內丹的醫學科學

A Consolidated Analysis of Mechanisms, Clinical Evidence, Disease Applications, and Anti-Ageing Effects

機制、臨床證據、疾病應用與抗衰老效益之綜合分析

An integrative, multi-scale review bridging traditional Chinese internal alchemy and contemporary biomedical research

融合中國傳統內丹術與當代生物醫學研究的多尺度整合評述

Acupoint Fascial Mechanotransduction · Mast-Cell Signal Transduction · the Ca^{2+}/ATP Axis · the HIF-1α–Sirtuin-1 Anti-Ageing Cascade · the Psychoneuroimmunology Model

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English Edition

全文繁體中文版

Abstract

Qigong is a traditional Chinese mind-body practice that integrates slow movement (dong gong), static postures (jing gong), regulated breathing, and focused mental concentration. Its highest and most inward dimension—Neidan, or internal alchemy—progressively reduces and ultimately eliminates external movement, directing the practitioner's attention inward toward the dantian energy centres, the microcosmic orbit, and specific acupoints, while breathing is deliberately slowed to an extreme degree or briefly suspended. This paper integrates two complementary sources: the first, a medical analysis of Qigong and Neidan weighted toward clinical evidence and disease-specific mechanisms; the second, a scholarly review weighted toward cellular-molecular mechanisms and anti-ageing biology, built upon a backbone of peer-reviewed literature.

Taken together, the available evidence supports a coherent multi-scale model in which Qigong movement and Neidan breath–intention work activate overlapping but distinct signalling cascades that converge upon the mast cell at the acupoint as a core cellular transducer. At the clinical level, randomized controlled trials and meta-analyses show that Qigong significantly lowers perceived stress and anxiety, modulates immune and inflammatory biomarkers, improves sleep and quality of life, and produces measurable benefits across conditions such as hypertension, type 2 diabetes, and chronic pain. At the mechanistic level, slow movement drives Ca^{2+}-dependent degranulation and ATP release in acupoint mast cells via fascial mechanotransduction and Piezo1/2 channels, modulating the autonomic nervous system (raising vagal tone and heart rate variability), the HPA axis (lowering cortisol), and the immune system (reducing pro-inflammatory cytokines and NF-κB signalling). Neidan-specific breath retention, via brief hypoxia, stabilizes HIF-1α, triggers a trophic activation of mast cells, and engages a longevity programme along the HIF-1α→Sirtuin-1 axis—up-regulating telomerase, reducing oxidative stress, attenuating the senescence-associated secretory phenotype (SASP), and protecting endothelial cells. On this basis, the paper proposes a unified framework in which biological ageing is slowed at genomic, neuroendocrine, immune, and tissue levels, illustrated with sciatica and eczema as worked clinical examples.

Keywords: Qigong, Neidan, dantian, acupoints, meridians, mast cells, mechanotransduction, the

摘要

氣功是一門融合緩慢動作（動功）、靜態樁法（靜功）、調息與精神專注的中國傳統身心修煉；其最高階、最內向的維度——內丹（內部煉金術）——則逐漸減少乃至消除外部動作，將修煉者的注意力向內導引至丹田、小周天與特定穴位，同時將呼吸刻意放緩至極深程度或暫時停止。本文整合兩份互補的資料：其一為偏重臨床證據與疾病特異性機制的氣功與內丹醫學分析，其二為偏重細胞分子機制與抗衰老生物學、並以同行評審文獻為骨幹的學術評述。

綜合而言，現有證據支持一個連貫的多尺度模型：氣功動作與內丹呼吸—意念工作激活相互交疊但各具特色的級聯反應，並共同匯聚於穴位處的肥大細胞這一核心細胞轉換器。在臨床層面，隨機對照試驗與統合分析顯示氣功能顯著降低知覺壓力與焦慮、調節免疫與發炎生物標記、改善睡眠與生活品質，並在高血壓、第二型糖尿病、慢性疼痛等多種疾病中產生可測量的益處。在機制層面，緩慢動作經由筋膜力學傳導與 Piezo1/2 通道驅動穴位肥大細胞的鈣離子（Ca^{2+}）依賴脫顆粒與 ATP 釋放，調節自律神經（提高迷走神經張力與心率變異度）、HPA 軸（降低皮質醇）與免疫系統（降低促發炎細胞因子與 NF-κB 訊號）。內丹特有的閉氣則經由短暫缺氧穩定 HIF-1α，觸發肥大細胞的滋養性激活，並沿 HIF-1α→Sirtuin-1 軸啟動長壽程序——上調端粒酶、減少氧化壓力、衰減衰老相關分泌表型（SASP）、保護內皮細胞。本文據此提出一個從基因組、神經內分泌、免疫到組織層面共同延緩生物衰老的統一框架，並以坐骨神經痛與濕疹為例說明其臨床應用。

關鍵詞：氣功、內丹、丹田、穴位、經絡、肥大細胞、力學傳導、Ca^{2+}/ATP 軸、HIF-1α、閉氣、Sirtuin-

Ca^{2+}/ATP axis, HIF-1α, breath retention, Sirtuin-1, vagal tone, HPA axis, psychoneuroimmunology, telomerase, oxidative stress, SASP, anti-ageing	1、迷走神經張力、HPA 軸、心理神經免疫學、端粒酶、氧化壓力、SASP、抗衰老

On citation style: Bracketed numbers (e.g. [1]) denote the principal peer-reviewed references, listed in full at the end of the paper; several additional meta-analyses and clinical trials cited in the text are identified directly by their study size and effect size so that readers may verify them.

關於引用體例：本文以方括號編號（如 [1]）標示經同行評審之主要參考文獻，完整書目見文末；文中另引述之多項統合分析與臨床試驗，其研究規模與效應量已於內文直接標明，以供讀者查證。

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1. Introduction

The relationship between Qigong practice and health has been recognized in Chinese civilization for at least two and a half millennia. Qigong—literally "the cultivation of vital energy"—encompasses a family of methods characterized by slow, conscious flowing movements, static standing or seated postures, and breath regulation coordinated with mental concentration. Neidan represents the highest and most inward dimension of this tradition: external movement is progressively reduced and ultimately eliminated, the practitioner's full attention is directed inward toward the dantian energy centres, the microcosmic orbit, and specific acupoints, while breathing is deliberately slowed to an extreme depth or stopped entirely. Traditional Chinese medicine (TCM) holds that both Qigong and Neidan cultivate and circulate "qi" through a network of meridians, with particular emphasis on the three dantian—the lower (below the navel), middle (at the heart), and upper (between the brows)—which serve respectively as reservoirs of jing (essence), qi (energy), and shen (spirit).

Contemporary biomedical research has now produced extensive evidence that these practices generate measurable physiological changes: altered electrical conductance along the meridians, autonomic nervous system regulation, shifts in immune-cell populations, reduced pro-inflammatory cytokines, up-regulated telomerase activity, lowered oxidative-stress biomarkers—and the precise modulation of mast-cell behaviour at acupoints. These findings are not merely correlational; controlled trials, randomized controlled trials, and mechanistic studies have begun to map the specific pathways responsible, making it possible to chart the ancient practices of Qigong and Neidan onto a coherent cellular and molecular framework.

At the core of this framework is the mast cell. Since Song Yong-kui first proposed in 1977 that the high density of mast cells at acupoints is not incidental but functionally significant [18], a growing body of research has established the mast cell as a principal mediator of acupoint signalling—responding both to the mechanical forces of Qigong movement and to the hypoxic, autonomic, and interoceptive signals specifically generated by Neidan breath retention and dantian intention. The mast cell thus emerges as a cellular

1. 緒論

氣功修煉與健康的關係在中國文明中已有至少兩千五百年的認識歷史。氣功——字面意義為「生命能量的修煉」——涵蓋一系列以緩慢有意識的流動動作、靜態站立或坐姿，以及與精神集中相協調的調息為特徵的方法。內丹代表這一傳統中最高階、最向內的維度：外部動作逐漸減少乃至消除，修煉者全部注意力向內導引至丹田能量中心、小周天及特定穴位，同時呼吸被刻意放緩至極深程度或完全停止。傳統中醫（TCM）認為，氣功與內丹均在修煉並使「氣」通過由經絡構成的網絡循環，並特別強調三個丹田——下丹田（臍下）、中丹田（心處）、上丹田（眉心）——分別作為精、氣、神的儲藏之所。

當代生物醫學研究現已產生大量證據，顯示這些修煉能產生可測量的生理變化：沿經絡的電導率改變、自律神經系統調節、免疫細胞群體變化、促發炎細胞因子降低、端粒酶活性上調、氧化壓力生物標記降低——以及穴位處肥大細胞行為的精確調節。這些發現並非僅屬相關性；對照試驗、隨機對照試驗及機制研究已開始描繪具體負責的通路，使得將氣功與內丹的古老修煉映射到連貫的細胞與分子框架之上成為可能。

本框架的核心是肥大細胞。自宋永奎於 1977 年首次提出穴位處肥大細胞高密度分佈並非偶然、而是具有功能意義以來 [18]，日益增多的研究已確立肥大細胞作為穴位信號傳導主要介質的地位——既響應氣功動作的機械力，也響應內丹閉氣及丹田意念所特別產生的缺氧、自律與內感受信號。肥大細胞因而作為細胞層面的「羅塞塔石碑」出現：將來自修煉的身體、自

"Rosetta Stone": translating the diverse inputs from the physical, autonomic, and intentional dimensions of practice into a unified language of tissue signalling, immune modulation, and anti-ageing molecular cascades. This paper first establishes the theoretical and anatomical foundations (Part I), then sequentially develops the cellular-molecular mechanisms (Part II), the systemic physiological effects (Part III), the anti-ageing molecular mechanisms (Part IV), the clinical evidence and disease applications (Part V), and finally an integrated model and outlook (Part VI).

律及意念維度的多元輸入，翻譯為組織信號、免疫調節及抗衰老分子級聯的統一語言。本文先建立理論與解剖基礎（第一部），再依序展開細胞分子機制（第二部）、系統性生理效應（第三部）、抗衰老分子機制（第四部）、臨床證據與疾病應用（第五部），最後提出整合模型與展望（第六部）。

2. Theoretical Foundations of Qigong and Neidan in Traditional Chinese Medicine | 2. 氣功與內丹的傳統中醫理論基礎

Qigong is rooted in the fundamental principles of TCM, which regards health as a state of harmonious flow and balance of the body's vital energy. Its key theoretical pillars include:

- **Qi (vital energy):** the basic life force flowing through the network of meridians throughout the body. Health depends on the unobstructed flow of qi; disease arises from its blockage, deficiency, or imbalance.
- **Yin–Yang philosophy:** all things can be understood as complementary opposites that must be balanced for optimal function. Qigong movements aim to harmonize the body's yin (passive, cooling, contracting) and yang (active, warming, expanding) qualities.
- **Meridian theory:** the meridians are invisible channels through which qi travels, each corresponding to a specific internal organ; Qigong seeks to stimulate and regulate these channels.
- **The Three Regulations:** traditional Qigong theory organizes practice around three interwoven components—regulating the body (correct posture and movement), regulating the breath (deep, slow, abdominal breathing), and regulating the mind (meditative focus, visualization, and intention).

氣功植根於傳統中醫的基本原則，中醫將健康視為體內生命能量和諧流動與平衡的狀態。關鍵理論支柱包括：

- **氣（生命能量）：**在全身經絡網絡中流動的基本生命力。健康取決於氣的暢通；疾病源於氣的阻塞、不足或不平衡。
- **陰陽哲學：**萬物皆可理解為互補的對立面，須平衡以達最佳功能。氣功動作旨在協調身體的陰（被動、冷卻、收縮）與陽（主動、溫熱、擴張）特質。
- **經絡理論：**經絡是氣運行的無形通道，每條對應特定的內臟器官；氣功旨在刺激並調節這些通道。
- **三調：**傳統氣功理論將練習圍繞三個相互交織的組成部分——調身（正確的姿勢與動作）、調息（深慢的腹式呼吸）、調心（冥想專注、觀想與意念）。

Neidan further centres on the three dantian: the lower stores jing, the middle stores qi, and the upper stores shen. As discussed below, these three energy centres correspond anatomically to richly innervated connective-tissue regions with unusually high mast-cell density, allowing the ancient vocabulary of "cultivating

內丹進一步以三丹田為核心：下丹田藏精、中丹田藏氣、上丹田藏神。如後文所述，這三個能量中心在解剖上分別對應神經支配豐富、肥大細胞密度異常高的結締組織區域，使得「培育丹田」這一古老語彙得以

the dantian" to acquire a cellular-level empirical correlate. Modern science offers potential biological interpretations of these traditional concepts: the mechanical stimuli generated by controlled breathing and postural stretch create pressure gradients that stimulate the lymphatic and interstitial-fluid systems (which may correspond to the meridian network described in TCM); Qigong has also been described as a form of "traditional vegetative (autonomic) biofeedback therapy," conditioning positive physiological responses through the repeated linkage of intention and bodily state.

在細胞層級獲得實證對應。現代科學研究為這些傳統概念提供了潛在的生物學解釋：由控制呼吸與姿勢拉伸產生的機械刺激會形成壓力梯度，刺激淋巴與間質液系統（可能對應中醫所述的「經絡網絡」）；氣功也被描述為一種「傳統植物性（自律神經）生物反饋療法」，透過意念與身體狀態的重複聯結，條件化出積極的生理反應。

3. Acupoints and Meridians: Anatomical and Bioelectrical Basis | 3. 穴位與經絡：解剖學與生物電基礎

3.1 Structural Specificity of Acupoints

The physiological significance of acupoints rests on their structural difference from surrounding tissue. Histological and imaging studies confirm that acupoints consistently show a higher density of connective-tissue condensation, neurovascular bundles, and free nerve endings; electron microscopy reveals aggregations of mast cells in perivascular and subdermal locations at classical acupoints. The gap junctions between connective-tissue fibroblasts at acupoints are denser, forming a low-impedance electrically-coupled network. Ultrasound and MRI studies have identified fascial cleavage planes corresponding to meridian trajectories, suggesting that the meridian system is at least in part a network of connective-tissue planes propagating mechanical and bioelectrical signals.

3.1 穴位的結構特殊性

穴位的生理意義建立在其與周圍組織的結構差異之上。組織學與影像學研究證實，穴位處一貫顯示更高密度的結締組織凝縮、神經血管束及游離神經末梢；電子顯微鏡揭示經典穴位處的血管周圍及真皮下位置存在肥大細胞聚集。穴位處結締組織成纖維細胞間的間隙連接更為密集，形成低阻抗電耦合網絡。超聲及 MRI 研究已識別出與經絡走行相對應的筋膜裂隙平面，提示經絡系統至少部分是傳播機械與生物電信號的結締組織平面網絡。

3.2 Meridian Conductance

The higher electrical conductance of meridian acupoints relative to surrounding skin reflects a higher water content within the connective-tissue condensation, more abundant gap junctions, and ion channels on the surfaces of mast cells and keratinocytes. Lin et al. (2018) demonstrated that a single session of Qigong significantly increased conductance in twelve of the fourteen classical meridians while simultaneously improving sympathetic–vagal balance and reducing anxiety [1]. This provides direct evidence that Qigong movement can produce measurable changes at acupoints within a single session. Notably, conductance changes are more durable and pronounced in experienced practitioners than in novices—suggesting

3.2 經絡電導率

經絡穴位相對周圍皮膚的較高電導率，反映了結締組織凝縮中更高的水分含量、更多的間隙連接，以及肥大細胞與角質形成細胞表面的離子通道。Lin 等人（2018 年）證實，單次氣功練習顯著提高了十四條經典經絡中十二條的電導率，並同時改善交感—迷走平衡並降低焦慮 [1]。這直接提供了氣功動作在單次練習中即可於穴位處產生可測量變化的證據。值得注意的是，與初學者相比，有經驗的修煉者的電導率變化更持久且更顯著——提示多年丹田專注修煉在經絡電學特性上產生了持久的結構重塑，這與長期穴位刺

that years of dantian-focused practice produce a lasting structural remodelling of the meridians' electrical properties, consistent with the mast-cell density changes and connective-tissue reorganization that accompany long-term acupoint stimulation.

激所伴隨的肥大細胞密度變化及結締組織重組相一致。

3.3 The Primo Vascular System

The primo vascular system (PVS)—a network of fine ducts distinct from blood and lymphatic vessels—has been proposed as the physical correlate of the meridian network, potentially serving as a conduit for liquid signalling molecules along meridian trajectories [2]. In the context of Neidan practice, the sustained intra-abdominal and intra-thoracic pressure changes produced by breath retention and lower-abdominal contraction may stimulate circulation within this system, helping to distribute mast-cell-derived mediators—nerve growth factor (NGF), vascular endothelial growth factor (VEGF), histamine, and serotonin (5-HT)—along the microcosmic-orbit pathway.

3.3 原始血管系統

原始血管系統（PVS）——一種有別於血液和淋巴管的細微管道網絡——已被提議作為經絡網絡的實體對應物，可能作為沿經絡走行的液態信號分子的傳導通路 [2]。在內丹修煉的背景下，由閉氣及下腹部肌肉收縮所產生的持續腹腔內與胸腔內壓力變化，可能刺激該系統的循環，有助於沿小周天路徑分佈肥大細胞來源的介質——神經生長因子（NGF）、血管內皮生長因子（VEGF）、組織胺與血清素（5-HT）。

Part II　Cellular and Molecular Mechanisms ｜ 第二部　細胞與分子機制

4. Mast Cells at the Acupoint: The Core Signal Transducer ｜ 4. 穴位處的肥大細胞：核心信號轉換器

4.1 Song's 1977 Hypothesis and Subsequent Validation ｜ 4.1 宋永奎 1977 年的假說與後續驗證

Song Yong-kui's (1977) key contribution was systematic histochemical proof that the density of mast cells at classical acupoints is significantly higher than in surrounding tissue [18]. Song proposed that this non-random distribution is functionally significant—that mast cells, by virtue of their capacity to degranulate under mechanical stimulation and to release potent vasoactive and neuroactive mediators, can serve as cellular transducers linking the physical inputs at acupoints to the systemic responses attributed to "qi activation." This prescient hypothesis has been broadly validated in the decades since. Plum et al. (2024) further characterized the mast cell as a "signal transducer" positioned at the interface of tissue state, immune state, and the nervous system [11]—a characterization that applies precisely to its acupoint role in Qigong and Neidan.

宋永奎（1977 年）的關鍵貢獻在於系統性組織化學證明：與周圍組織相比，經典穴位處的肥大細胞密度顯著更高 [18]。宋氏提出，這種非隨機分佈具有功能意義——肥大細胞憑藉其在機械刺激下脫顆粒的能力及釋放強效血管活性與神經活性介質的特性，可作為細胞轉換器，連接穴位處的物理輸入與「氣激活」所歸因的系統性反應。這一具有先見之明的假說在此後數十年間得到了廣泛驗證。Plum 等人（2024 年）更將肥大細胞定性為位於組織狀態、免疫狀態及神經系統交界處的「信號轉換器」[11]——此一定性精確適用於其在氣功與內丹中的穴位角色。

4.2 Mechanotransduction and Mediator Release at the Acupoint ｜ 4.2 穴位處的力學傳導與介質釋放

When Qigong movement applies sustained, low-amplitude deformation to the connective tissue overlying an acupoint, mechanosensitive receptors are activated. Piezo1 and Piezo2 ion channels on mast cells mediate calcium influx in response to membrane stretch; the resulting Ca^{2+} signal drives degranulation and the release of the following principal mediators:

當氣功動作對穴位上方的結締組織施加持續的低振幅形變時，機械敏感受體被激活。肥大細胞上的 Piezo1 與 Piezo2 離子通道介導響應膜牽張的鈣離子內流；由此產生的 Ca^{2+} 信號驅動脫顆粒並釋放以下主要介質：

Mediator released by mast cells 肥大細胞釋放的介質	Principal action 主要作用
Tryptase 類胰蛋白酶（Tryptase）	Activates PAR-2 on C-fibres, producing the afferent "deqi" signal and deep sensation 活化 C 纖維上的 PAR-2，產生傳入性「得氣」信號與深層感覺
Histamine 組織胺（Histamine）	Dilates local microvessels via H1 receptors; activates unmyelinated afferents 經 H1 受體擴張局部微血管；激活無髓鞘傳入神經
Serotonin (5-HT) 血清素（5-HT）	Activates 5-HT3 receptors on nociceptive fibres 激活傷害感覺纖維上的 5-HT3 受體
Nerve growth factor (NGF) 神經生長因子（NGF）	Promotes the growth and maintenance of nerve fibres at the acupoint 促進穴位處神經纖維生長與維持

Vascular endothelial growth factor (VEGF) 血管內皮生長因子（VEGF）	Promotes local angiogenesis and tissue repair 促進局部血管新生與組織修復
Prostaglandin E2 / D2 (PGE2 / PGD2) 前列腺素 E2 / D2（PGE2 / PGD2）	Vasodilation; promotes local hyperaemia 血管擴張、促進局部充血

4.3 Mast-Cell–Nerve Coupling and Bidirectional Modulation | 4.3 肥大細胞—神經偶聯與雙向調節

Electron microscopy shows that mast cells at acupoints lie in intimate apposition to unmyelinated nerve endings—as close as 20 nanometres, near enough for paracrine signalling without intervening extracellular matrix. This bidirectional neuroimmune connection permits both bottom-up (mechanical→mast cell→nerve) and top-down (nerve→mast cell) modulation. In Neidan practice, the top-down pathway is of particular importance, for it provides the cellular substrate for "guiding qi with intention"—using mental intention to direct neural efferent activity and thereby modulate mast-cell behaviour at the acupoint.

電子顯微鏡顯示，穴位處的肥大細胞與無髓鞘神經末梢在最近 20 奈米的距離內緊密毗鄰——近至無需中間細胞外基質即可進行旁分泌信號傳導。這種雙向神經免疫連接允許自下而上（機械→肥大細胞→神經）與自上而下（神經→肥大細胞）的調節。在內丹修煉中，自上而下的通路具有特別重要的意義，因為它為「以意導氣」提供了細胞基底——通過精神意念引導神經傳出活動，從而調節穴位處的肥大細胞行為。

4.4 Acupoint Sensitization and Desensitization | 4.4 穴位敏化與去敏化

Acupoints are dynamic biosensors whose sensitivity varies with physiological state. Pathological states over-sensitize acupoints by expanding the mast-cell population, lowering the degranulation threshold, and increasing local tryptase, 5-HT, and NGF expression. Regular Qigong and Neidan practice, through its normalizing effects on the autonomic nervous system, cortisol levels, and systemic inflammation, gradually desensitizes pathologically activated acupoints—a homeostatic feedback mechanism that restores acupoint and visceral function to physiological baseline. The nature of the output—from homeostatic trophic signalling, to inflammatory activation, to SASP-amplifying pathological degranulation—depends on the integrated state of these inputs; regular practice biases the mast cell toward a homeostatic, trophic state.

穴位是動態生物感測器，其敏感性隨生理狀態而變化。病理狀態通過擴大肥大細胞群體、降低脫顆粒閾值並增加局部類胰蛋白酶、5-HT 及 NGF 表達，使穴位過度敏化。規律氣功與內丹修煉通過其對自律神經系統、皮質醇水平及系統性發炎的正常化效應，逐漸使病理性激活的穴位去敏化——這是一種將穴位及臟腑功能恢復至生理基線的自穩態反饋機制。輸出的性質——從自穩態滋養性信號、到發炎激活、再到 SASP 放大性病理性脫顆粒——取決於這些輸入的整合狀態；規律修煉使肥大細胞偏向自穩態滋養性狀態。

5. The Fascial Substrate of the Meridians and Five Parallel Mechanical Pathways | 5. 經絡的筋膜基底與五條同步力學通路

Fascia—the continuous connective-tissue network enveloping muscles, organs, vessels, and nerves—is now the leading candidate physical substrate for the meridian system. A 2015 study established the fascial-deformation link between connective-tissue mechanotransduction and acupoint function [2]. Picard

筋膜——包繞肌肉、臟器、血管及神經的連續結締組織網絡——現在是經絡系統最主要的候選實體基底。2015 年的一項研究確立了結締組織力學傳導與穴位

et al. (2017) identified five parallel mechanical pathways by which Qigong stimulates the meridians [3]:

- **Fascial stretch and recoil:** sustained slow stretch activates slowly-adapting Ruffini endings and interstitial C-fibre afferents—mechanoreceptors optimized to respond to low-amplitude sustained deformation, precisely the force signature produced by Qigong movement.
- **Connective-tissue mechanotransduction:** fibroblasts release growth factors in response to strain and communicate through gap junctions, transmitting signals along fascial planes.
- **Visceral massage:** rhythmic abdominal compression stimulates mechanoreceptors on the visceral peritoneum and mesentery, promoting autonomic regulation.
- **Craniosacral pump:** rhythmic axial skeletal oscillation produces small-amplitude cerebrospinal-fluid pressure fluctuations, providing mechanical stimulation to the central nervous system.
- **Lymphatic return:** rhythmic muscular contraction promotes lymphatic circulation, enhancing immune surveillance.

In Neidan practice, the first and third pathways are especially enhanced: lower-abdominal contraction during dantian breathing and breath retention produces greater intra-abdominal pressure fluctuations than external movement, generating stronger mechanotransduction signals at peri-visceral acupoints (Guanyuan CV4, Qihai CV6, Zhongwan CV12) and in subperitoneal mast-cell populations. In standard Qigong, slow diaphragmatic breathing at 4–6 breaths per minute shifts autonomic tone toward parasympathetic dominance by stimulating pulmonary stretch receptors and the Hering–Breuer reflex; in Neidan, breathing rate may fall to 1–2 cycles per minute or stop entirely during retention, entering an additional physiological dimension (most notably the hypoxic signalling cascade) that external movement alone cannot reach.

功能之間的筋膜形變連接 [2]。Picard 等人（2017 年）識別出氣功刺激經絡的五條並行力學通路 [3]：

- **筋膜牽張與回縮**：持續緩慢牽張激活緩慢適應的魯菲尼氏末梢及間質 C 纖維傳入神經——這些機械感受器優化響應低振幅持續形變，正是氣功動作的力量特徵。
- **結締組織力學傳導**：成纖維細胞響應應變釋放生長因子並通過間隙連接通訊，沿筋膜面傳遞信號。
- **內臟按摩**：節律性腹部壓迫刺激內臟腹膜及腸繫膜上的機械感受器，促進自律神經調節。
- **顱骶泵**：節律性軸向骨骼振盪產生小振幅腦脊液壓力波動，為中樞神經系統提供機械刺激。
- **淋巴回流**：節律性肌肉收縮促進淋巴循環，增強免疫監視。

在內丹修煉中，第一條與第三條通路特別得到增強：丹田呼吸與閉氣期間的下腹部收縮產生比外部動作更大的腹腔內壓力波動，在內臟周圍穴位（關元 CV4、氣海 CV6、中脘 CV12）及腹膜下肥大細胞群體產生更強的力學傳導信號。在標準氣功中，每分鐘 4–6 次的緩慢橫膈膜呼吸通過刺激肺牽張感受器與海林—布魯爾反射，使自律神經張力向副交感神經優勢轉移；在內丹中，呼吸頻率可降至每分鐘 1–2 個週期，或在閉氣階段完全停止，進入額外的生理維度（最顯著的是缺氧信號級聯），這是單獨的外部動作所無法達到的。

6. Mechanotransduction → the Ca^{2+}/ATP Axis: A Consolidated Local Amplification Loop | 6. 機械轉導 → Ca^{2+}/ATP 軸：統合的局部放大環路

The acupoint mechanotransduction described above can be integrated into a core local amplification loop that is simultaneously the common hub of both source

前述穴位力學傳導可整合為一條核心的局部放大環路，它同時是本文兩份來源資料的共同樞紐：機械輸

documents underlying this paper: mechanical input → cellular deformation → ATP release → purinergic P2X/P2Y receptor activation → Ca^{2+} influx → mast-cell degranulation → mediator release → local and systemic effects. This cascade is not a single pathway but the "master control knob" of the autonomic–neuroendocrine–immune axis; the various diseases discussed later are, at their mechanistic root, dysregulations of one or more nodes along this cascade.

入 → 細胞形變 → ATP 釋放 → 嘌呤能 P2X / P2Y 受體激活 → Ca^{2+} 內流 → 肥大細胞脫顆粒 → 介質釋放 → 局部及系統性效應。此級聯並非單一路徑，而是自律神經—神經內分泌—免疫軸的「總控制旋鈕」；後文所討論的多種疾病，在其機制根源上，都是此級聯上某個或某些節點的失調。

Mechanotransduction and the Ca^{2+}/ATP Signalling Cascade at the Acupoint

穴位處的機械轉導與 Ca^{2+}/ATP 訊號級聯

Practice input: slow Qigong movement / Neidan breath retention & respiration	**練習輸入：氣功緩慢動作 / 內丹閉氣與呼吸**
↓	↓
Mechanical stimulus (sustained loading of acupoint fascia)	**機械刺激（穴位筋膜的持續負荷）**
↓	↓
Piezo1 / 2 mechanically-gated ion channels open	**Piezo1 / 2 機械門控離子通道開啟**
↓	↓
Intracellular Ca^{2+} rises (triggers mast-cell degranulation)	**細胞內 Ca^{2+} 上升（觸發肥大細胞脫顆粒）**
↓	↓
ATP release → P2X / P2Y purinergic receptor activation	**ATP 釋放 → P2X / P2Y 嘌呤受體活化**
↓	↓
Neural current (autonomic signalling)	**神經電流（自律神經訊號）**
↓	↓
Hypothalamus / brainstem integration	**下視丘 / 腦幹整合**

Convergence of systemic and anti-ageing effects: autonomic (HRV ↑, vagal tone ↑, cortisol ↓); neuroendocrine (HPA down-regulation, IL-6 ↓ / IL-10 ↑); genomic (telomerase/TERT ↑, SASP ↓); vascular (eNOS → nitric oxide [NO] → endothelial protection). Each output node of this diagram corresponds to the cellular basis of the systemic effects (Part III) and the anti-ageing mechanisms (Part IV) discussed below.

全身性與抗老化效應的匯流：自律神經（心率變異度 ↑、迷走神經張力 ↑、皮質醇 ↓）；神經內分泌（HPA 下調、IL-6 ↓ / IL-10 ↑）；基因層級（端粒酶 TERT ↑、SASP ↓）；血管（eNOS → 一氧化氮 NO → 內皮保護）。此圖的每一輸出節點，皆對應後文系統性效應（第三部）與抗衰老機制（第四部）的細胞基礎。

7. Neidan-Specific Mechanism (I): Breath Retention, Hypoxia, and the HIF-1α–Mast-Cell Axis | 7. 內丹特有機制（一）：閉氣、缺氧與 HIF-1α–肥大細胞軸

7.1 The Physiology of Breath Retention and HIF-1α Stabilization | 7.1 閉氣的生理學與 HIF-1α 穩定化

When the breath is held or greatly slowed in Neidan practice, two synchronous physiological events occur. First, alveolar oxygen tension (PO_2) falls while carbon-dioxide tension (PCO_2) rises—producing a controlled, transient tissue-hypoxia signal even when the lungs are full of air, because oxygen consumption continues in a closed or near-closed system. Second, the cessation of thoracic movement eliminates the main driver of respiratory sinus arrhythmia, briefly lowering heart rate and increasing vagal efferent discharge (a diving-reflex-type parasympathetic response). The critical cellular consequence of this transient hypoxia is the stabilization of HIF-1α (hypoxia-inducible factor 1α): under normal oxygen tension, HIF-1α is continuously hydroxylated by prolyl-hydroxylase domain (PHD) enzymes and targeted for proteasomal degradation via the VHL pathway; even a few seconds of hypoxia inhibit PHD, allowing HIF-1α to accumulate and translocate to the nucleus, where it activates the hypoxia-response-element (HRE) transcriptional programme.

在內丹修煉中屏息或大幅放緩呼吸時，兩個同步生理事件發生。首先，肺泡氧分壓（PO_2）下降而二氧化碳分壓（PCO_2）上升——即使肺部充滿空氣，耗氧在封閉或近封閉系統中持續進行，也會產生受控、短暫的組織缺氧信號。其次，胸廓運動的停止消除了呼吸竇性心律不整的主要驅動力，短暫降低心率並增加迷走傳出放電（潛水反射型副交感反應）。這種短暫缺氧的關鍵細胞後果是 HIF-1α（缺氧誘導因子 1α）的穩定化：在正常氧分壓下，HIF-1α 被脯胺醯羥化酶（PHD）持續羥基化並經 VHL 通路靶向降解；即使數秒的缺氧也會抑制 PHD，允許 HIF-1α 積累並轉位入核，激活缺氧反應元件（HRE）轉錄程序。

7.2 HIF-1α in Mast Cells: Trophic Activation | 7.2 肥大細胞中的 HIF-1α：滋養性激活

HIF-1α is expressed in mast cells and directly regulates their activation, degranulation, and cytokine production. Research has established that HIF-1α promotes degranulation and up-regulates VEGF and TGF-β in mast cells; silencing HIF-1α reduces degranulation and down-regulates these growth factors [21]. Crucially, the HIF-1α-mediated activation programme is entirely distinct from the IgE/FcεRI allergic activation programme: it drives a trophic, growth-factor-releasing degranulation (dominated by VEGF, TGF-β, NGF, and calibrated amounts of histamine) rather than the histamine-dominated allergic pattern. At the acupoint—where mast cells are coupled to nerve endings and blood vessels—this HIF-1α-driven trophic activation constitutes the precise cellular mechanism for maintaining the structural and functional integrity of the acupoint: keeping nerve endings healthy, local microvessels responsive, and fascial tissue in a state of readiness for remodelling.

HIF-1α 在肥大細胞中表達，直接調節其激活、脫顆粒及細胞因子產生。研究確立 HIF-1α 在肥大細胞中促進脫顆粒並上調 VEGF 與 TGF-β；沉默 HIF-1α 則降低脫顆粒並下調這些生長因子 [21]。關鍵在於，HIF-1α 介導的肥大細胞激活程序與 IgE / FcεRI 過敏激活程序截然不同：它驅動滋養性、釋放生長因子的脫顆粒（以 VEGF、TGF-β、NGF 及校準量的組織胺為主），而非組織胺主導的過敏反應模式。在穴位處——肥大細胞與神經末梢及血管耦合——這種 HIF-1α 驅動的滋養性激活，構成維持穴位結構與功能完整性的確切細胞機制：保持神經末梢健康、局部微血管反應性，以及筋膜組織的重塑準備狀態。

7.3 HIF-1α as an Anti-Ageing Longevity Factor and the Sirtuin-1 Axis | 7.3 HIF-1α 作為抗衰老長壽因子與 Sirtuin-1 軸

The anti-ageing significance of transient HIF-1α activation is now established. Mehta et al. (2009) showed that HIF-1 stabilization is associated with a 30–50% extension of lifespan in Caenorhabditis elegans; subsequent mammalian studies confirmed that regular, transient HIF-1α activation (as distinct from chronic pathological hypoxia) promotes endothelial repair, mitochondrial biogenesis (via PGC-1α), and resistance to vascular ageing [22]. The crucial distinction is this: intermittent, controlled HIF-1α activation (as in Neidan breath retention) produces hormetic anti-ageing benefits, whereas chronic pathological hypoxia (as in obstructive sleep apnoea or tissue ischaemia) produces oxidative stress and SASP. By virtue of its controlled, conscious, intermittent character, Neidan breath retention provides beneficial HIF-1α pulses without the oxidative damage of sustained hypoxia—mechanistically equivalent to the documented anti-ageing benefits of altitude training and intermittent hypoxic conditioning, but achieved through respiratory self-regulation.

The HIF-1α → Sirtuin-1 axis is particularly relevant: Sirtuin-1, a key longevity deacetylase activated downstream of HIF-1α, promotes mitochondrial biogenesis, deacetylates HIF-1α itself (forming a feedback-regulatory loop), regulates endothelial nitric oxide synthase (eNOS) and nitric-oxide (NO) production, and counteracts endothelial-cell senescence. Through this cascade, Neidan breath retention activates a Sirtuin-1-dependent longevity programme at the very moment that mast cells at the dantian acupoints receive their trophic HIF-1α degranulation signal—a mechanism that recurs throughout the anti-ageing discussion in Part IV.

一過性 HIF-1α 激活的抗衰老意義現已確立。Mehta 等人（2009 年）證示 HIF-1 穩定化與秀麗隱桿線蟲壽命延長 30–50%相關；後續哺乳動物研究確認，規律、短暫的 HIF-1α 激活（有別於慢性病理性缺氧）促進內皮修復、線粒體生物合成（經 PGC-1α）及抵禦血管衰老 [22]。關鍵區別在於：間歇性、受控的 HIF-1α 激活（如內丹閉氣）產生激素興奮型（hormetic）抗衰老效益；而慢性病理性缺氧（如阻塞性睡眠呼吸中止或組織缺血）則產生氧化壓力與 SASP。內丹閉氣憑藉其受控、有意識、間歇性的特點，提供有益的 HIF-1α 脈衝而不帶來持續缺氧的氧化損傷——在機制上等同於高原訓練與間歇性缺氧調節的抗衰老效益，但通過呼吸自我調節達成。

HIF-1α → Sirtuin-1 軸尤為相關：Sirtuin-1 作為 HIF-1α 下游激活的關鍵長壽去乙醯化酶，促進線粒體生物合成、使 HIF-1α 本身去乙醯化（形成反饋調節環路）、調節內皮型一氧化氮合酶（eNOS）及一氧化氮（NO）產生，並對抗內皮細胞衰老。內丹閉氣通過這一級聯，在丹田穴位處的肥大細胞同時接收滋養性 HIF-1α 脫顆粒信號的確切時刻，激活了依賴 Sirtuin-1 的長壽程序——此一機制將反覆貫穿第四部的抗衰老討論。

8. Neidan-Specific Mechanism (II): CO_2 Vasodilation and Mast-Cell Priming Along the Microcosmic Orbit | 8. 內丹特有機制（二）：CO_2 血管擴張與小周天沿線的肥大細胞啟動

Neidan breath retention also produces a rise in PCO_2 (hypercapnia). CO_2 acts as a potent vasodilator at the arteriolar level, both by directly relaxing smooth muscle and by stimulating eNOS to increase NO production; at acupoints—where neurovascular bundles are dense—this vasodilation is especially pronounced. The resulting increase in local blood flow delivers oxygen and nutrients to acupoint mast cells, warms the acupoint tissue (the subjective warmth and tingling felt along the microcosmic orbit during Neidan practice is the

內丹閉氣也產生 PCO_2 上升（高碳酸血症）。CO_2 通過直接舒張平滑肌及刺激 eNOS 增加 NO 產生，作為強效血管擴張劑在小動脈水平發揮作用；在神經血管束密集的穴位處，這種血管擴張尤為顯著。由此產生的局部血流增加：為穴位處肥大細胞輸送氧氣與養分、使穴位組織升溫（內丹修煉中沿小周天感受到的主觀溫熱與刺麻感，正是 CO_2 驅動血管擴張與肥大細

experiential correlate of CO_2-driven vasodilation together with mast-cell-mediated histamine and PGE2 release), and increases the mechanical distension of local vessel walls, further activating Piezo1 mechanosensitive channels and driving additional controlled Ca^{2+} influx and tonic mediator release.

The classical descriptions of practice in Neidan texts such as the Huangting Jing—warmth, a sense of fullness, and a pulsatile progression from the lower dantian up the Governing Vessel (Du Mai) to the crown of the head and back down the Conception Vessel (Ren Mai) to the dantian—correspond precisely to the vascular anatomy along which a CO_2 wave spreads from the lower abdomen (where metabolic activity is greatest and PCO_2 rises most during abdominal retention) upward along the spinal and cranial vasculature, thereby sequentially activating mast-cell populations. This is not to reduce Neidan phenomenology entirely to mast-cell histamine—the experience is richer than any single mediator—but the warm, pulsatile, tingling quality of the "qi sensation" is consistent with, and mechanistically explained by, the controlled vasodilation and sensory-nerve activation produced by sequential CO_2-driven mast-cell activation. Zhang et al. (2023) further proposed that Qigong produces an oxygen-supply and acid–base balance against potential pathological hypoxia by simultaneously increasing oxygen delivery, reducing consumption, and improving microcirculation, with the key cellular mechanisms being the HIF-1α→Sirtuin-1 pathway, lactate signalling via HCAR1, AMPK activation, and the restoration of mitochondrial oxidative phosphorylation [19].

胞介導之組織胺、PGE2 釋放的體驗性對應物）、並增加局部血管壁的機械擴張，進一步激活 Piezo1 機械敏感通道而驅動額外的受控 Ca^{2+} 內流與緊張性介質釋放。

《黃庭經》等內丹典籍對修煉的經典描述——溫熱、充盈感及從下丹田沿督脈至頭頂、再沿任脈回至丹田的搏動性進展——精確對應 CO_2 波沿這些經絡走行的血管解剖學從下腹部（腹部閉氣時代謝活動最強、PCO_2 升幅最大之處）向上沿脊柱與顱骨血管擴散，從而依序激活肥大細胞群體。這並非要將內丹現象學完全歸結為肥大細胞組織胺——該體驗比任何單一介質都更豐富——但「氣感」的溫熱、搏動、刺麻性質，與 CO_2 驅動的肥大細胞依序激活所產生的受控血管擴張及感覺神經激活相一致並得到機制解釋。Zhang 等人（2023 年）進一步提出，氣功通過同時增加氧供、減少耗氧並改善微循環，針對潛在病理性缺氧產生氧供與酸鹼平衡，關鍵細胞機制為 HIF-1α→Sirtuin-1 通路、經 HCAR1 的乳酸信號、AMPK 激活及線粒體氧化磷酸化的恢復 [19]。

9. Neidan-Specific Mechanism (III): Intention, Yi, and Top-Down Acupoint Modulation | 9. 內丹特有機制（三）：意念、意與自上而下的穴位調節

9.1 Yi (Intention) as a Neural Efferent Signal | 9.1 意（意）作為神經傳出信號

The Neidan concept of yi—directing intention or awareness toward specific acupoints and dantian regions—is not merely a metaphysical notion but has a neural basis. Sustained focused attention on an internal bodily location activates specific cortical networks: the anterior insula (interoceptive cortex), the anterior cingulate cortex, and the somatosensory cortex corresponding to the attended body region. These activations produce efferent autonomic signals via the cortico–hypothalamic–autonomic axis, altering local blood flow, temperature, and neural efferent activity at the attended site. Research has shown that long-term

內丹中「意」的概念——將意念或覺知導向特定穴位與丹田區域——不僅是形而上學概念，更有神經基礎。對內部身體位置的持續集中注意激活特定的皮質網絡：前島葉（內感受皮質）、前扣帶皮質，以及與被注意身體區域對應的軀體感覺皮質。這些激活通過皮質—下視丘—自律神經軸產生傳出自律神經信號，改變被注意部位的局部血流、溫度及神經傳出活動。研究已證明長期深腹呼吸可「溫和地調節並強化迷走

deep abdominal breathing "gently tones and strengthens the vagus nerve," while focused lower-dantian attention "can deliver energy to the energy centres via a diaphragmatic mechanism," improving visceral circulation—from a neuroscientific standpoint, this reflects the fact that directing awareness to the lower dantian increases parasympathetic efferent discharge to the mesenteric plexus, altering the mast-cell activation state in the subperitoneal connective tissue.

神經」，而集中的下丹田注意「可通過橫膈膜機制向能量中心輸送能量」，改善臟器循環——從神經科學角度，這反映了將覺知導向下丹田增加了對腸繫膜叢的副交感傳出放電，改變腹膜下結締組織中的肥大細胞激活狀態。

9.2 GV4 Mingmen: the Gate of Life and Adrenal-Cortical Regulation | 9.2 GV4 命門：生命之門與腎上腺皮質調節

Mingmen (GV4, the "Gate of Life") lies on the Governing Vessel between L2 and L3, behind the lower dantian, and is one of the most important acupoints in Neidan practice—associated in TCM with kidney yang, reproductive vitality, and original qi (yuan qi). Anatomically, GV4 lies over the lumbar sympathetic ganglia and the adrenal projections of the spinal cord (T10–L1 splanchnic nerves). Sustained Neidan attention to Mingmen—particularly the focus on the posterior lower dantian in standing-post (Zhan Zhuang) practice—activates the cortico-autonomic projections that regulate adrenal-cortical output. This has direct anti-ageing consequences: lowered basal cortisol → up-regulated telomerase → telomere protection, and reduced cortisol-driven SASP → attenuation of the inflammaging programme. The TCM characterization of Mingmen as the source of the "fire of life" is, within this biomedical framework, a description of the adrenal–mitochondrial axis that drives metabolic vitality and, when dysregulated, accelerates biological ageing.

命門（GV4，生命之門）位於督脈 L2 與 L3 之間的下丹田後方，是內丹修煉中最重要的穴位之一——在中醫中與腎陽、生殖活力及元氣相關。從解剖學角度，GV4 位於腰部交感神經節與脊髓（T10–L1 內臟神經）腎上腺投射之上。持續的內丹對命門的注意——特別是在站樁修煉中專注於後下丹田——激活調節腎上腺皮質輸出的皮質—自律神經投射。這具有直接的抗衰老後果：基礎皮質醇降低 → 端粒酶上調 → 端粒保護，以及過量皮質醇驅動的 SASP 降低 → 炎性衰老程序的衰減。中醫對命門作為「生命之火源泉」的表述，在此生物醫學框架中，是對驅動代謝活力、並在失調時加速生物衰老的腎上腺—線粒體軸的描述。

9.3 GV20 Baihui, Yintang, and the HPA Feedback Loop | 9.3 GV20 百會、印堂與 HPA 反饋環路

The crown point Baihui (GV20) and the upper dantian Yintang (EX-HN3), typically attended to in the completion of the microcosmic orbit, lie directly over the prefrontal cortex and the pituitary–hypothalamic axis. Sustained Neidan attention to these points—particularly during the descending phase along the Conception Vessel—activates inhibitory prefrontal projections to the hypothalamus, directly lowering corticotropin-releasing hormone (CRH) secretion and HPA-axis drive. This is the neuroanatomical basis of the well-documented cortisol-lowering effect of meditation and advanced Qigong: by consciously focusing on the upper dantian and the crown, the practitioner activates the prefrontal–

頭頂穴百會（GV20）與上丹田印堂（EX-HN3），通常在小周天完成中被關注，直接位於前額葉皮質及垂體—下視丘軸附近之上。在內丹中對這些穴位的持續注意——特別是在任脈的下行階段——激活前額葉對下視丘的抑制性投射，直接降低促腎上腺皮質激素釋放激素（CRH）分泌與 HPA 軸驅動。這是有據可查的冥想與高階氣功降低皮質醇效應的神經解剖學基礎：修煉者通過有意識地集中於上丹田與頭頂，在源頭激

hypothalamic feedback loop at its source, thereby down-regulating their own stress response.

活前額葉—下視丘反饋環路，從而下調自身的壓力反應。

Part III Systemic Physiological Effects | 第三部 系統性生理效應

10. The Autonomic Nervous System and Heart Rate Variability | 10. 自律神經系統與心率變異性

10.1 Qigong, Neidan, and Heart Rate Variability | 10.1 氣功、內丹與心率變異性

Heart rate variability (HRV)—the beat-to-beat variation in cardiac inter-beat intervals—is the principal non-invasive index of autonomic function. The meta-analysis by Larkey et al. (2024) found that Tai Chi and Qigong practice significantly improved HF power (SMD = 0.29, p = 0.003) and SDNN (SMD = 0.83, p = 0.02) [4]; these effect sizes are comparable to pharmacological interventions and reflect a genuine shift of autonomic balance toward vagal dominance. In Neidan practitioners, HRV improvement may substantially exceed that of the general Qigong population, because the extreme respiratory slowing of advanced Neidan (1–2 cycles per minute) produces the maximal respiratory sinus arrhythmia—the strongest physiological driver of HF HRV; at these breathing rates, nearly every cardiac cycle is coupled to the respiratory rhythm, producing the coherent, large-amplitude HRV oscillations associated with optimal autonomic function.

心率變異度（HRV）——心搏間隔的逐拍變化——是自律神經功能的主要非侵入性指標。Larkey 等人（2024 年）的統合分析發現，太極與氣功修煉顯著改善 HF 功率（SMD = 0.29，p = 0.003）與 SDNN（SMD = 0.83，p = 0.02）[4]；這些效應量可與藥理學干預相媲美，反映自律神經平衡向迷走神經優勢的真實轉變。在內丹修煉者中，HRV 改善可能大幅超過一般氣功人群，因為高階內丹的極度呼吸放緩（每分鐘 1–2 個週期）產生最大的呼吸竇性心律不整——HF HRV 最強的生理驅動力；在這些呼吸頻率下，幾乎每個心動週期都與呼吸節律耦合，產生與最佳自律神經功能相關的連貫、大振幅 HRV 振盪。

10.2 The Vagal Anti-Inflammatory Pathway and Mast-Cell Stabilization | 10.2 迷走神經抗發炎通路與肥大細胞穩定化

The increased vagal tone brought about by regular practice exerts a direct effect on mast-cell biology via the cholinergic anti-inflammatory pathway (CAP). Acetylcholine released from vagal nerve endings binds the nicotinic α7 receptor (α7nAChR) on macrophages and mast cells, inhibiting the release of pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6. The direct vagus–mast-cell communication has been anatomically confirmed: vagal afferents penetrate the small-intestinal mucosa and form close contacts with intestinal mucosal mast cells; vagotomy reduces mast-cell density (indicating a trophic relationship); and vagal stimulation modulates mast-cell histamine and serotonin content [20].

This pathway is especially important for Neidan: sustained slow or arrested breathing maximizes vagal tone at the precise anatomical locations—the lower dantian and the mesenteric plexus, the very sites where mucosal mast cells are densest. The result is an elegantly

規律修煉所帶來的迷走神經張力增加，通過膽鹼能抗發炎通路（CAP）對肥大細胞生物學產生直接影響。從迷走神經末梢釋放的乙醯膽鹼與巨噬細胞及肥大細胞上的菸鹼型 α7 受體（α7nAChR）結合，抑制 TNF-α、IL-1β、IL-6 等促發炎細胞因子的釋放。迷走神經—肥大細胞的直接通訊已在解剖學上得到證實：迷走傳入神經穿入小腸黏膜並與腸黏膜肥大細胞形成密切接觸；迷走神經切除術降低肥大細胞密度（顯示存在滋養關係）；迷走神經刺激調節肥大細胞的組織胺與血清素含量 [20]。

這一通路對內丹尤為重要：持續緩慢或停止的呼吸，在解剖學精確位置——下丹田、腸繫膜叢，亦即黏膜肥大細胞最密集之處——最大化迷走神經張力。結果

resolved paradox: breath retention creates a transient hypoxic stimulus via HIF-1α that triggers controlled, trophic mast-cell activation, while the simultaneously increased vagal tone of slow or arrested exhalation stabilizes mast cells against inflammatory over-activation via α7nAChR. The two signals are complementary rather than contradictory, together defining the Neidan mast-cell state—trophically active, immunologically quiescent.

是一個優美解決的悖論：閉氣通過 HIF-1α 創造短暫缺氧刺激，觸發受控的肥大細胞滋養性激活；而緩慢或停止呼氣同時帶來的迷走神經張力增加，則經 α7nAChR 穩定肥大細胞對抗發炎過度激活。兩個信號互補而非矛盾，共同定義了內丹的肥大細胞狀態——滋養活躍，免疫靜息。

11. Stress, the HPA Axis, and Cortisol | 11. 壓力、HPA 軸與皮質醇

11.1 Immediate Effects on State Anxiety and Sustained Effects Across Populations | 11.1 對狀態焦慮的立即效果與不同人群的持續效果

Qigong rapidly reduces acute anxiety. In psychiatric inpatients, a single 40-minute session of Qigong significantly reduced state anxiety: the intervention group's mean post-test score was 27.20 versus 39.72 in controls, a highly statistically significant difference; a single 60-minute session of Baduanjin likewise significantly reduced anxiety and improved mood in young adults. As for sustained effects, a 12-week Neidan Qigong intervention in 332 university students showed lasting improvements in mindfulness, emotion regulation, perceived stress, depression, anxiety, and sleep quality, with those of lower baseline interoceptive ability and higher trait anxiety benefiting most. A 2024 systematic review of nine RCTs found that, compared with no treatment, Qigong significantly reduced perceived stress (odds ratio −0.60; 95% CI −1.02 to −0.17). The pooled evidence suggests that, to achieve optimal improvement in anxiety, practice should occur 3–4 times per week for 40–60 minutes over 12–16 weeks; for depression, a higher frequency (5–7 times per week) sustained beyond 24 weeks is more effective.

氣功能快速降低急性焦慮。在精神科住院病人中，一次 40 分鐘的氣功顯著降低狀態焦慮：介入組的平均後測分數為 27.20，對照組為 39.72，差異具高度統計顯著性；年輕成年人進行一次 60 分鐘的八段錦也能顯著降低焦慮並改善情緒。在持續效果方面，一項納入 332 名大學生的 12 週內丹氣功介入顯示，正念、情緒調節、知覺壓力、憂鬱、焦慮與睡眠品質均有持續改善，其中基線內感受能力較低、特質焦慮較高者受益最多。2024 年一項涵蓋九項 RCT 的系統性回顧發現，與無治療對照相比，氣功顯著降低知覺壓力（勝算比 −0.60；95% CI −1.02 至 −0.17）。統合證據建議，欲在焦慮上達最佳改善，宜每週練習 3–4 次、每次 40–60 分鐘、持續 12–16 週；憂鬱症則以更高頻率（每週 5–7 次）並持續超過 24 週效果更佳。

11.2 The HPA Axis, Cortisol, and Mechanisms | 11.2 HPA 軸、皮質醇與機制

Chronic HPA-axis activation raises cortisol, which suppresses immune function, promotes visceral-fat accumulation, inhibits neurogenesis, and accelerates telomere shortening. Van Dam (2020) reviewed evidence that Qigong lowers cortisol levels, promotes faster post-stress cortisol recovery, and improves subjective well-being [9]; a 2014 review established that acupuncture relieves HPA-axis over-activation by modulating glucocorticoid-receptor (GR) expression, CRH levels, and ACTH secretion [10]. Because Neidan activates acupoints on the Governing Vessel and the

慢性 HPA 軸激活升高皮質醇，抑制免疫功能、促進內臟脂肪積累、抑制神經新生並加速端粒縮短。Van Dam（2020 年）回顧了氣功降低皮質醇水平、促進壓力後皮質醇更快恢復及改善主觀幸福感的證據 [9]；2014 年的一篇綜述則確立針灸通過調節糖皮質激素受體（GR）表達、CRH 水平及 ACTH 分泌來緩解 HPA 軸過度激活 [10]。由於內丹通過與針刺相同的力學傳導與注意性機制激活督脈與心包經穴位，且修煉者可

pericardium meridian via the same mechanotransduction and attentional mechanisms as needle acupuncture, and because practitioners can sustain the stimulation over longer periods, it likely produces an even greater cumulative HPA-normalizing effect than brief needling. In sum, Qigong's stress relief operates by down-regulating the HPA axis (reducing cortisol), raising vagal tone and parasympathetic activation, retraining interoception, and cultivating mindful awareness of thoughts and emotions.

在較長時間維持刺激，故很可能產生比短暫針刺更大的累積 HPA 正常化效果。綜言之，氣功的壓力緩解經由下調 HPA 軸（減少皮質醇）、提升迷走神經張力與副交感活化、內感受再訓練，以及對想法與情緒的正念覺察而運作。

12. Immune Function and Inflammatory Regulation | 12. 免疫功能與發炎調節

12.1 Systematic Reviews and Cytokine Profiles | 12.1 系統評價與細胞因子譜

Yeung et al. (2020) confirmed that regular Tai Chi and Qigong produce beneficial changes across multiple dimensions of immune function: enhanced NK-cell activity, improved T-lymphocyte proliferation, modulation of immunoglobulin levels, and a shift in the circulating cytokine profile consistent with a transition from a pro-inflammatory to an anti-inflammatory phenotype [5]. The meta-analysis by Yu et al. (2025) found that mind-body interventions including Qigong produced sustained decreases in CRP, IL-6, TNF-α, IL-1, IL-8, and IL-17, with concurrent increases in IL-10, IFN-γ, BDNF, and secretory IgA [7]; the reductions in IL-6 and IL-8 are especially important, as both are major components of the senescent-cell SASP, implying that practice reduces the "inflammaging" burden driven by senescent-cell accumulation. Bower and Irwin (2016) reviewed evidence that mind-body therapies reduce NF-κB signalling—the master transcription factor of pro-inflammatory gene expression—and alter neuroendocrine pathways at the gene-expression level [8]; Neidan, which produces particularly deep parasympathetic engagement and cortisol reduction, may produce the most pronounced NF-κB inhibition of all Qigong modalities.

Yeung 等人（2020 年）證實規律太極與氣功在免疫功能多個維度產生有益變化：增強的 NK 細胞活性、改善的 T 淋巴細胞增殖、免疫球蛋白水平調節，以及與促發炎向抗發炎表型轉變一致的循環細胞因子譜改變 [5]。Yu 等人（2025 年）的統合分析發現，包括氣功在內的身心干預使 CRP、IL-6、TNF-α、IL-1、IL-8 與 IL-17 持續下降，同時 IL-10、IFN-γ、BDNF 與分泌型 IgA 增加 [7]；其中 IL-6 與 IL-8 的降低尤為重要，因為兩者皆為衰老細胞 SASP 的主要成分，意味著修煉降低了由衰老細胞積累驅動的「炎性衰老」負擔。Bower 與 Irwin（2016 年）回顧了身心療法降低 NF-κB 信號——促發炎基因表達的主要轉錄因子——並在基因表達水平改變神經內分泌通路的證據 [8]；內丹能產生特別深度的副交感參與與皮質醇降低，可能在所有氣功方式中產生最顯著的 NF-κB 抑制。

12.2 Immune Effects in Specific Practices and Disease Populations | 12.2 特定練習與疾病族群的免疫效果

In healthy subjects practising Guolin Qigong daily, researchers observed a significant increase in the IFNγ:IL-10 ratio (a shift toward type-1 cytokine dominance), together with altered IL-6 and TNFα expression and reduced blood cortisol. Alonso et al. (2023) found that a four-week Daoist Qigong programme (a tradition adjacent to Neidan) significantly

在每天練習郭林氣功的健康受試者中，研究觀察到 IFNγ:IL-10 比值顯著增加（向第一型細胞因子主導的轉變），同時 IL-6 與 TNFα 表達改變、血液皮質醇降低。Alonso 等人（2023 年）發現為期四週的道家氣功（與內丹鄰近的流派）顯著降低白血球總數，並改

reduced total leukocyte count and altered immunoglobulin (IgG, IgA, IgM) and complement-protein (C3, C4) levels, indicating modulation of both adaptive and innate immunity [6]. In fibromyalgia patients, four weeks of Qigong reduced the absolute counts of the CD3+, CD4+, CD8+, CD16+, and CD45+ lymphocyte subsets while increasing the CD19+ percentage and complement C3; in older adults, 12 weeks of Wu Qin Xi reduced the circadian variation of stress hormones and inflammatory responses while enhancing immune function.

變免疫球蛋白（IgG、IgA、IgM）與補體蛋白（C3、C4）水平，提示適應性與先天性免疫均受調節 [6]。在纖維肌痛症患者中，四週氣功使 CD3+、CD4+、CD8+、CD16+、CD45+ 淋巴細胞亞群絕對計數減少，同時 CD19+ 百分比與補體 C3 增加；在老年人中，12 週五禽戲減少了壓力激素與發炎反應的晝夜變化並增強免疫功能。

12.3 Neuroinflammation and the Meta-Analytic Summary | 12.3 神經發炎與統合分析總結

A 2026 dose–response meta-analysis (29 RCTs, 2,253 participants with neuropsychiatric conditions) found that mind-body exercise (Qigong, Tai Chi, yoga, and mindfulness-based stress reduction) significantly reduced IL-6 (SMD = −0.47) and IL-1β (SMD = −0.90) while increasing IL-10 (SMD = 0.87) and BDNF (SMD = 1.08), with an optimal anti-inflammatory dose of 600–1000 MET-minutes per week and the greatest neurotrophic benefit for Qigong. Another meta-analysis of 19 RCTs (1,686 participants) found that Tai Chi and Qigong produced a significant small effect on increasing immune-cell levels (SMD = 0.28; 95% CI 0.13 to 0.43), while the overall effect on systemic inflammation did not reach significance (SMD = −0.15)—a finding that likely reflects the subtle, bidirectional nature of immune modulation (which "boosts" or "calms" depending on baseline state) rather than simple linear suppression, and which corresponds precisely to the integrated mast-cell state of being "trophically active, immunologically quiescent" described above.

一項 2026 年的劑量反應統合分析（29 項 RCT、2,253 名神經精神疾病參與者）發現，身心運動（氣功、太極、瑜伽與正念減壓）顯著降低 IL-6（SMD = −0.47）與 IL-1β（SMD = −0.90），同時增加 IL-10（SMD = 0.87）與 BDNF（SMD = 1.08），最佳抗發炎劑量為每週 600–1000 MET-分鐘，且氣功在神經營養結果上益處最大。另一項納入 19 項 RCT（1,686 名參與者）的統合分析發現，太極與氣功在增加免疫細胞水平方面產生顯著的小效應（SMD = 0.28；95% CI 0.13 至 0.43），而對全身性發炎的總體效果未達顯著（SMD = −0.15）——這可能反映免疫調節的細微、雙向性質（取決於基線狀態而「增強」或「鎮靜」），而非單純的線性抑制，恰與前述肥大細胞「滋養活躍、免疫靜息」的整合狀態相呼應。

13. Neuroplasticity, BDNF, and the Psychoneuroimmunology Model | 13. 神經可塑性、BDNF 與心理神經免疫學模型

Regular Qigong practice, and especially the inward meditative focus of Neidan, has been associated with structural and functional changes in the central nervous system. BDNF up-regulation—documented across several studies included in the Yu et al. (2025) meta-analysis [7]—promotes hippocampal neurogenesis, enhances synaptic plasticity, and resists age-related loss of cortical grey matter. Neidan's BDNF up-regulation occurs via multiple convergent pathways: cortisol reduction (which inhibits hippocampal BDNF), increased vagal tone, HIF-1α activation of neuroprotective gene expression, and the Sirtuin-1 activation that

規律氣功修煉，尤其是內丹向內的冥想專注，已與中樞神經系統的結構與功能變化相關聯。BDNF 上調——在 Yu 等人（2025 年）統合分析所含的多項研究中有記錄 [7]——促進海馬神經新生、增強突觸可塑性並抵禦年齡相關的皮質灰質流失。內丹的 BDNF 上調通過多條匯聚通路發生：皮質醇降低（其抑制海馬 BDNF）、迷走神經張力增加、HIF-1α 激活神經保護性基因表達，以及伴隨閉氣 HIF-1α 脈衝的 Sirtuin-1 激活；這些通路的結合——在多年日常修煉中持續維持

accompanies the breath-retention HIF-1α pulse; the combination of these pathways—sustained across years of daily practice—may produce the structural brain differences documented in experienced meditators: increased prefrontal grey matter, enhanced interoceptive-cortex volume, and larger hippocampal structures.

——可能產生有經驗冥想者所記錄的結構性大腦差異：增加的前額葉灰質、增強的內感受皮質體積、更大的海馬結構。

A systematic review of movement-oriented mind-body interventions for psychological stress and trauma examined 20 studies with objective physiological measures, most of which found that improvements in mental health were accompanied by positive effects on inflammatory and immune processes. The diagram below synthesizes the proposed psychoneuroimmunology (PNI) mechanisms, linking the autonomic, neuroendocrine, and immune nodes described above into a coherent multi-level model:

一項針對以動作為導向、用於心理壓力與創傷的身心干預系統性回顧，檢視了 20 項含客觀生理指標的研究，多數發現心理健康改善伴隨對發炎與免疫過程的正面影響。下圖綜合了所提出的心理神經免疫學（PNI）機制，將前述自律、神經內分泌與免疫節點串聯為一個連貫的多層模型：

The Psychoneuroimmunology (PNI) Model of Qigong

氣功的心理神經免疫學（PNI）模型

Psychological level **Mindful awareness, body scan, interoception, visualization**	**心理層面** **正念覺察、身體掃描、內感受、觀想**
↓	↓
Neural level **↑ prefrontal cortical regulation; ↓ amygdala reactivity** **↑ vagal tone (parasympathetic / HPA down-regulation)**	**神經層面** **↑ 前額葉皮質調節；↓ 杏仁核反應性** **↑ 迷走神經張力（副交感 / HPA 軸下調）**
↓	↓
Endocrine level **↓ cortisol, ↓ catecholamines; ↑ DHEA, ↑ melatonin**	**內分泌層面** **↓ 皮質醇、↓ 兒茶酚胺；↑ DHEA、↑ 褪黑激素**
↓	↓
Immune level **↓ pro-inflammatory cytokines (IL-6, TNF-α, IL-1β)** **↑ anti-inflammatory cytokines (IL-10)** **↑ immune-cell activity (NK cells, lymphocytes)** **modulation of inflammation-related gene expression (NF-κB)**	**免疫層面** **↓ 促發炎細胞因子（IL-6、TNF-α、IL-1β）** **↑ 抗發炎細胞因子（IL-10）** **↑ 免疫細胞活性（NK 細胞、淋巴細胞）** **調控發炎相關基因表達（NF-κB）**
↓	↓
Health outcomes **↓ stress, ↓ anxiety / depression, ↓ pain** **↑ sleep quality, ↑ quality of life, ↓ chronic-disease risk**	**健康結果** **↓ 壓力、↓ 焦慮 / 憂鬱、↓ 疼痛** **↑ 睡眠品質、↑ 生活品質、↓ 慢性病風險**

14. Telomere Biology and Telomerase | 14. 端粒生物學與端粒酶

Telomeres—the repetitive DNA sequences $(TTAGGG)_n$ that cap the ends of eukaryotic chromosomes—shorten with each cell division; on reaching a critical minimum, the cell enters replicative senescence or apoptosis. Chronic stress is one of the strongest inhibitors of telomerase (the enzyme that replenishes telomeric repeats); cortisol-driven telomere attrition is the direct molecular mechanism linking psychological stress to accelerated biological ageing. An RCT by Chan et al. (2012) in chronic-fatigue-syndrome patients found that four months of Qigong significantly increased telomerase activity in peripheral blood mononuclear cells, with the effect correlating with improvements in fatigue, depression, and anxiety [12]; Tiwari et al. (2014) extended the findings across populations, showing that the telomerase increase was greatest in those with higher baseline stress [13]; and a 2022 complementary meditation study demonstrated that three months of regular practice provided significant protection against telomere shortening [14].

端粒——帽護真核生物染色體末端的重複 DNA 序列（$TTAGGG)_n$——隨每次細胞分裂縮短，達到關鍵最低限度時細胞進入複製性衰老或凋亡。慢性壓力是端粒酶（補充端粒重複序列的酶）活性最強的抑制因素之一；皮質醇驅動的端粒縮減是將心理壓力與加速生物衰老相連接的直接分子機制。Chan 等人（2012 年）在慢性疲勞症候群患者中的 RCT 發現，四個月的氣功顯著增加外周血單核細胞的端粒酶活性，且效應與疲勞、憂鬱、焦慮的改善相關 [12]；Tiwari 等人（2014 年）將發現延伸至多個人群，顯示端粒酶增加在基線壓力較高者中最為顯著 [13]；一項 2022 年的補充冥想研究亦證明三個月規律修煉提供顯著的端粒縮短防護 [14]。

Neidan provides an additional route to telomerase up-regulation via an entirely distinct pathway: the breath-retention-activated HIF-1α → Sirtuin-1 cascade has direct epigenetic consequences relevant to telomere biology. Sirtuin-1, an NAD^+-dependent deacetylase, deacetylates and thereby activates the catalytic subunit of telomerase, telomerase reverse transcriptase (TERT). Regular intermittent HIF-1α activation through Neidan breath retention may therefore directly stimulate telomerase activity by maintaining Sirtuin-1 expression and activity—complementing and amplifying the cortisol-reduction pathway. This represents a Neidan-specific anti-ageing mechanism unobtainable through external-movement Qigong alone.

內丹更通過一條截然不同的通路為端粒酶上調提供額外途徑：閉氣激活的 HIF-1α → Sirtuin-1 級聯具有與端粒生物學相關的直接表觀遺傳後果。Sirtuin-1 是一種 NAD^+ 依賴的去乙醯化酶，使端粒酶催化亞基——端粒酶逆轉錄酶（TERT）——去乙醯化並由此激活它。通過內丹閉氣的規律間歇性 HIF-1α 激活，藉維持 Sirtuin-1 的表達與活性，可能直接刺激端粒酶活性——補充並放大皮質醇降低通路。這代表了一種僅通過外部動作氣功無法獲得的內丹特有抗衰老機制。

15. Oxidative Stress and Antioxidant Defence | 15. 氧化壓力與抗氧化防禦

Chronic oxidative stress—an excess of reactive oxygen species (ROS) exceeding cellular antioxidant capacity—drives the hallmarks of ageing: cellular senescence, mitochondrial dysfunction, epigenomic alterations, and loss of proteostasis. The principal enzymatic antioxidants (SOD, GPX, catalase) decline with age, while lipid-peroxidation products (MDA) accumulate. A network meta-analysis by Chen et al. (2022) found Wu Qin Xi to

慢性氧化壓力——超過細胞抗氧化能力的過量活性氧（ROS）——驅動衰老的標誌特徵：細胞衰老、線粒體功能障礙、表觀基因組改變及蛋白質穩態喪失。主要酶抗氧化劑（SOD、GPX、過氧化氫酶）隨年齡下降，而脂質過氧化產物（MDA）積累。Chen 等人（2022 年）的網絡統合分析發現，五禽戲在增加老

be the most effective at increasing SOD and GPX activity and lowering MDA in older adults, followed by Baduanjin and Yijinjing, with effect sizes comparable to moderate-intensity aerobic exercise [15].

Neidan breath retention contributes to antioxidant defence via the HIF-1α → PGC-1α axis: transient HIF-1α activation up-regulates PGC-1α, driving mitochondrial biogenesis, increasing mitochondrial number and efficiency, and up-regulating mitochondrial SOD (MnSOD, encoded by SOD2—a HIF-1α target gene). The net effect is more efficient electron-transport-chain function (less electron "leakage" forming superoxide), higher mitochondrial antioxidant capacity, and reduced mitochondrial ROS. Zhang et al. (2023) confirmed that the recovery-breathing phase of Qigong restores mitochondrial oxidative phosphorylation, shifting cellular metabolism from glycolytic back to aerobic and lowering the lactate accumulation and acidic tissue environment that drive pro-inflammatory mast-cell behaviour at acupoints [19].

年人 SOD 與 GPX 活性及降低 MDA 方面最為有效，其次是八段錦與易筋經，效應量與中等強度有氧運動相當 [15]。

內丹閉氣則通過 HIF-1α → PGC-1α 軸對抗氧化防禦作出貢獻：一過性 HIF-1α 激活上調 PGC-1α，驅動線粒體生物合成，增加線粒體數量與效率，並上調線粒體 SOD（MnSOD，由 SOD2 基因編碼——一個 HIF-1α 靶基因）。最終效果是更高效的電子傳遞鏈功能（更少電子「洩漏」形成超氧化物）、更高的線粒體抗氧化能力與更少的線粒體 ROS。Zhang 等人（2023 年）確認，氣功的恢復呼吸階段恢復了線粒體氧化磷酸化，使細胞從糖酵解代謝轉回有氧代謝，降低了驅動穴位處肥大細胞促發炎行為的乳酸積累與酸性組織環境 [19]。

16. Cellular Senescence and the SASP | 16. 細胞衰老與 SASP

When cells undergo replicative or stress-induced premature senescence, they secrete the senescence-associated secretory phenotype (SASP)—a suite of pro-inflammatory cytokines, growth factors, and proteases (IL-1, IL-6, IL-8, MMP-3, MMP-9, PAI-1)—that drives inflammaging and induces bystander senescence in neighbouring cells, and is a major driver of tissue dysfunction in ageing organs. Qigong's well-documented reductions in IL-6, IL-8, TNF-α, and MMP activity suggest that it attenuates SASP expression in senescent cells. Neidan's additional HIF-1α → Sirtuin-1 activation contributes further: Sirtuin-1 inhibits NF-κB (the master transcription factor of SASP gene expression) and deacetylates p53, lowering activation of the senescence programme. The result is a dual SASP-attenuating mechanism in Neidan—top-down via vagal/cortisol reduction of NF-κB, and bottom-up via Sirtuin-1-mediated NF-κB deacetylation.

當細胞經歷複製性或壓力誘導的提前衰老時，它們分泌衰老相關分泌表型（SASP）——一系列促發炎細胞因子、生長因子與蛋白酶（IL-1、IL-6、IL-8、MMP-3、MMP-9、PAI-1）——驅動炎性衰老並在鄰近細胞中誘導旁觀者衰老，是衰老器官組織功能障礙的主要驅動力。氣功對 IL-6、IL-8、TNF-α 及 MMP 活性的有據可查的降低，提示其在衰老細胞中衰減 SASP 表達。內丹額外的 HIF-1α → Sirtuin-1 激活進一步作出貢獻：Sirtuin-1 抑制 SASP 基因表達的主要轉錄因子 NF-κB，並使 p53 去乙醯化、降低衰老程序激活。結果是內丹雙重的 SASP 衰減機制——自上而下通過迷走神經 / 皮質醇降低 NF-κB，以及自下而上通過 Sirtuin-1 介導的 NF-κB 去乙醯化。

17. Mast Cells, Senescence, and Skin Biology | 17. 肥大細胞、衰老與皮膚生物學

Wicaksono et al. (2025) demonstrated a mast-cell-mediated causal chain between vascular endothelial-cell senescence and skin ageing [17]: endothelial-cell senescence (driven by oxidative stress and telomere shortening) leads to SASP activation → senescent

Wicaksono 等人（2025 年）證明了血管內皮細胞衰老與皮膚衰老之間由肥大細胞介導的因果鏈 [17]：內皮細胞衰老（由氧化壓力與端粒縮短驅動）導致 SASP 激活 → 衰老內皮細胞與血管周圍神經纖維釋放 SASP

endothelial cells and perivascular nerve fibres release SASP-derived calcitonin gene-related peptide (CGRP) → CGRP binds receptors on dermal mast cells, triggering degranulation → mast-cell tryptase and MMP-9 degrade dermal collagen and elastin → dermal thinning, loss of elasticity, and wrinkle formation. Pharmacological mast-cell stabilization attenuated these ageing phenotypes, confirming that mast-cell activity is a causal driver of skin ageing.

Qigong and Neidan address every link in this chain simultaneously:

- lowering cortisol and oxidative stress → reducing endothelial-cell senescence and telomere shortening;
- raising vagal tone → α7nAChR-mediated stabilization of dermal mast cells;
- lowering IL-6 and TNF-α (SASP suppression) → reducing CGRP released by senescent endothelial cells;
- HIF-1α → eNOS → NO → endothelial protection and functional maintenance;
- Sirtuin-1 activation → counteracting endothelial-cell senescence at the epigenetic level.

Neidan's additional HIF-1α–Sirtuin-1 axis specifically targets the endothelial-cell-senescence entry point of this cascade, providing a Neidan-specific skin anti-ageing mechanism by protecting endothelial health in the dermal microvascular bed.

來源的降鈣素基因相關肽（CGRP）→ CGRP 與真皮肥大細胞上的受體結合、觸發脫顆粒 → 肥大細胞類胰蛋白酶與 MMP-9 降解真皮膠原蛋白與彈性蛋白 → 真皮變薄、彈性喪失與皺紋形成。藥理性肥大細胞穩定化減輕了這些衰老表型，確認肥大細胞活性是皮膚衰老的因果驅動因素。

氣功與內丹同時解決這一鏈條的每個環節：

- 降低皮質醇與氧化壓力 → 減少內皮細胞衰老與端粒縮短；
- 增加迷走神經張力 → α7nAChR 介導的真皮肥大細胞穩定化；
- 降低 IL-6、TNF-α（SASP 抑制）→ 減少衰老內皮細胞釋放的 CGRP；
- HIF-1α → eNOS → NO → 內皮保護與功能維持；
- Sirtuin-1 激活 → 在表觀遺傳水平對抗內皮細胞衰老。

內丹額外的 HIF-1α–Sirtuin-1 軸特別針對這一級聯的內皮細胞衰老入口點，通過在真皮微血管床保護內皮健康，提供了一種內丹特有的皮膚抗衰老機制。

18. The Microcosmic Orbit as a Mast-Cell Activation Circuit | 18. 小周天作為肥大細胞激活迴路

The microcosmic orbit of Neidan traces two of the eight extraordinary meridians: the Governing Vessel (Du Mai), ascending from the perineum along the posterior midline to the crown of the head, and the Conception Vessel (Ren Mai), descending from the crown along the anterior midline to the perineum. Both vessels traverse the regions of highest mast-cell density in the body—the Governing Vessel passing through sacral-foramen mast-cell clusters, the lumbar-fascial plexus, epidural spinal connective tissue, dural mast cells surrounding the cranial venous sinuses, and cranial-suture periosteal mast cells; the Conception Vessel passing through the lower-dantian subperitoneal plexus (CV4/CV6), the thymic–sternal connective tissue (CV17), pharyngeal submucosal mast cells (CV22), and lower-facial

內丹的小周天追蹤奇經八脈中的兩條：督脈（從會陰沿後正中線升至頭頂）與任脈（從頭頂沿前正中線降至會陰）。兩條脈均穿越體內肥大細胞密度最高的區域——督脈經骶孔肥大細胞簇、腰筋膜叢、硬膜外脊柱結締組織、圍繞顱靜脈竇的硬膜肥大細胞與顱縫骨膜肥大細胞；任脈經下丹田腹膜下叢（CV4 / CV6）、胸腺—胸骨結締組織（CV17）、咽喉黏膜下肥大細胞（CV22）與下面部骨膜肥大細胞。當修煉者沿小周天循環覺知並同時閉氣時，高碳酸血症性血管擴張的 CO_2 波、HIF-1α 滋養性肥大細胞激活脈衝與迷走神經穩定信號，均沿這些相同的解剖學通路依序傳

periosteal mast cells. When the practitioner circulates awareness along the microcosmic orbit while holding the breath, the CO_2 wave of hypercapnic vasodilation, the trophic HIF-1α mast-cell-activation pulse, and the vagal stabilizing signal all propagate sequentially along these same anatomical pathways; the subjective warmth and fullness the practitioner feels along the orbit is the sensory signature of this sequential wave of mast-cell activation.

播；修煉者沿軌道感受到的溫熱與充盈，正是這種依序肥大細胞激活波的感覺特徵。

The systemic distribution of mast cells along the microcosmic orbit means that regular orbit practice not only modulates immunity or anti-ageing at specific visceral sites but systemically distributes trophic mast-cell signals (VEGF, NGF, TGF-β, and calibrated amounts of histamine) along the body's entire fascial axis, from sacrum to crown, providing a comprehensive tissue-maintenance signal—stimulating connective-tissue remodelling, maintaining nerve-fibre integrity, supporting local angiogenesis, and preserving the structural health of the fascial-meridian network—that no external-movement Qigong form can replicate with the same systemic reach.

沿小周天的肥大細胞系統性分佈意味著，規律的周天修煉不僅在特定臟器位置調節免疫或抗衰老，更沿身體整個筋膜軸系統性地分佈滋養性肥大細胞信號（VEGF、NGF、TGF-β 及校準量的組織胺），從骶骨到頭頂提供全面的組織維護信號——刺激結締組織重塑、維持神經纖維完整性、支持局部血管新生並維持筋膜經絡網絡的結構健康——這是任何外部動作氣功形式無法以相同系統性範圍複製的。

Part V Clinical Evidence, Disease Applications, and Case Analyses | 第五部 臨床證據、疾病應用與個案分析

19. Health Promotion and Quality of Life | 19. 健康促進與生活品質

A VA evidence map reviewed 25 systematic reviews published between 2014 and 2024 and found that the evidence base for Tai Chi and Qigong has grown substantially: two showed high-certainty benefit for hypertension and osteoporosis, and 16 showed moderate-certainty benefit spanning chronic low back pain, diabetes, depression, fall prevention, and knee osteoarthritis. For sleep, a meta-analysis of 15 RCTs (1,074 older adults) found a pooled PSQI total-score improvement of −2.47 points (95% CI −3.09 to −1.85), with Baduanjin especially effective (MD = −2.89) and larger effects in sleep-disorder (−3.30), depression (−1.96), and hypertension (−2.61) populations. For fatigue, a meta-analysis of 13 RCTs (661 participants) found that Qigong, Tai Chi, and yoga significantly reduced fatigue in patients with chronic fatigue syndrome or long COVID (SMD = −0.44; 95% CI −0.63 to −0.25). For chronic low back pain, a meta-analysis of 8 RCTs (729 participants) found significant reductions in pain intensity (SMD = −1.07) and disability (SMD = −0.77), with the certainty of evidence rated moderate to high.

一項 VA 證據地圖回顧了 2014 至 2024 年間發表的 25 篇系統性回顧，發現太極與氣功的證據基礎已顯著增長：兩篇顯示對高血壓與骨質疏鬆症具高確定性益處，16 篇顯示中等確定性益處，涵蓋慢性下背痛、糖尿病、憂鬱症、跌倒預防與膝骨關節炎等領域。在睡眠方面，一項納入 15 項 RCT、1,074 名老年人的統合分析發現 PSQI 總分合併改善 −2.47 分（95% CI −3.09 至 −1.85），其中八段錦尤其有效（MD = −2.89），且在睡眠障礙（−3.30）、憂鬱症（−1.96）與高血壓（−2.61）族群中效果更大。在疲勞方面，一項含 13 項 RCT（661 名參與者）的統合分析發現氣功、太極與瑜伽顯著減少慢性疲勞症候群或新冠後遺症患者的疲勞（SMD = −0.44；95% CI −0.63 至 −0.25）。在慢性下背痛方面，一項含八項 RCT（729 名參與者）的統合分析發現顯著降低疼痛強度（SMD = −1.07）與失能程度（SMD = −0.77），證據確定性評為中等到高。

20. Disease-Specific Mechanisms and Applications | 20. 疾病特異性機制與應用

The mechanotransduction → Ca^{2+}/ATP axis described above is not a single pathway but the master control knob of the autonomic–neuroendocrine–immune axis; the following diseases are, at their mechanistic root, dysregulations of certain nodes along this cascade. Each is described below in terms of its principal cascade node and key evidence (to avoid repetition, the molecular details are given in Parts II–IV).

前述機械轉導 → Ca^{2+}/ATP 軸並非單一路徑，而是自律神經—神經內分泌—免疫軸的總控制旋鈕；以下多種疾病在機制根源上，皆為此級聯上某些節點的失調。以下逐一說明其主要級聯節點與關鍵證據（為避免重複，分子細節參見第二至四部）。

20.1 Hypertension | 20.1 高血壓

The principal cascade node is neural → HPA axis → autonomic efferents → vascular tone. Sustained Qigong movement activates the Ruffini endings in the fascia overlying Guanyuan (CV4), Neiguan (PC6), and Zusanli (ST36), driving mast cells to release tryptase onto PAR-2

主要級聯節點為神經 → HPA 軸 → 自律神經傳出 → 血管張力。持續氣功動作活化關元（CV4）、內關（PC6）、足三里（ST36）上方筋膜的魯菲尼氏末梢，驅使肥大細胞釋放類胰蛋白酶至 PAR-2 傳入神

afferents that project to the nucleus tractus solitarius (NTS), shifting autonomic balance toward parasympathetic dominance and lowering peripheral vascular resistance and RAAS activation; Neidan breath retention provides short-latency vasodilation via CO_2→eNOS→NO and up-regulates eNOS via HIF-1α→Sirtuin-1. A meta-analysis of 20 RCTs (2,349 patients) showed that Qigong lowered systolic blood pressure by −17.4 mmHg and diastolic by −10.1 mmHg; when combined with antihypertensive medication, it added a further −12.0 mmHg of systolic reduction.

經，投射至孤束核（NTS）使自律神經轉向副交感主導、降低周邊血管阻力與 RAAS 活化；內丹閉氣經 CO_2→eNOS→NO 提供短潛伏期血管舒張，並經 HIF-1α→Sirtuin-1 上調 eNOS。一項納入 20 項 RCT（2,349 名患者）的統合分析顯示，氣功使收縮壓降低 −17.4 mmHg、舒張壓降低 −10.1 mmHg；與降血壓藥併用時額外增加 −12.0 mmHg 收縮壓降幅。

20.2 Asthma | 20.2 氣喘

The principal nodes are ATP release and P2Y receptors, but the cascade runs "in reverse"—Qigong inhibits pathological mast-cell degranulation. The vagal arc activates the cholinergic anti-inflammatory pathway via α7nAChR on bronchial mast cells, inhibiting IgE-triggered histamine and cysteinyl-leukotriene release; slow deep breathing lowers sympathetic drive to bronchial smooth muscle. Stimulating Feishu (BL13), Dazhui (GV14), and Zusanli (ST36) shifts the Th1/Th2 balance away from the IgE-promoting Th2-dominant state. For Neidan practitioners, extreme respiratory slowing activates HIF-1α in bronchial mast cells, producing a trophic (VEGF-, TGF-β-releasing) rather than histaminergic degranulation, supplying airway-mucosal repair signals without provoking bronchoconstriction.

主要節點為 ATP 釋放與 P2Y 受體，但級聯以「反向」運行——氣功抑制病理性的肥大細胞脫顆粒。迷走神經弧經支氣管肥大細胞上的 α7nAChR 活化膽鹼能抗發炎通路，抑制 IgE 觸發的組織胺與半胱胺醯白三烯釋放；緩慢深呼吸降低對支氣管平滑肌的交感驅動。刺激肺俞（BL13）、大椎（GV14）、足三里（ST36）可使 Th1 / Th2 平衡離開促進 IgE 的 Th2 主導狀態。對內丹練習者，極度呼吸減緩在支氣管肥大細胞啟動 HIF-1α，產生滋養性（釋放 VEGF、TGF-β）而非組織胺性的脫顆粒，在不引發支氣管收縮的情況下提供呼吸道黏膜修復訊號。

20.3 Type 2 Diabetes | 20.3 第二型糖尿病

The principal nodes are mechanical → neural → hypothalamus → autonomic control of pancreatic β-cells, plus skeletal-muscle GLUT4 translocation. Vagal dominance enhances insulin secretion; skeletal-muscle GLUT4 translocation is up-regulated by low-grade mechanical activation and Ca^{2+}-CaMKII signalling (independent of insulin); mast-cell mediator output suppressing IL-6, TNF-α, and NF-κB removes the inhibitory serine phosphorylation on IRS-1, restoring insulin-receptor sensitivity; and HPA normalization via GV20→prefrontal→hypothalamic feedback lowers cortisol-driven gluconeogenesis. A Tai Chi meta-analysis showed significant reductions in fasting plasma glucose (SMD −0.67) and HbA1c (MD −0.88%), with Qigong outperforming other aerobic exercise in HbA1c reduction.

主要節點為機械 → 神經 → 下視丘 → 胰臟 β 細胞自律控制，加上骨骼肌 GLUT4 轉位。迷走主導增強胰島素分泌；骨骼肌 GLUT4 轉位因低度機械活化與 Ca^{2+}-CaMKII 訊號上調（獨立於胰島素）；肥大細胞介質輸出對 IL-6、TNF-α、NF-κB 的抑制移除 IRS-1 上的抑制性絲胺酸磷酸化、恢復胰島素受體敏感性；經 GV20→前額葉→下視丘回饋使 HPA 正常化、降低皮質醇驅動的糖質新生。一項太極統合分析顯示空腹血漿葡萄糖顯著下降（SMD −0.67）、糖化血色素（HbA1c）下降（MD −0.88%），且氣功在 HbA1c 降幅上優於其他有氧運動。

20.4 Thyroid Disease, Migraine, and Mood Disorders

In thyroid disease, the hypothalamic–pituitary–thyroid (HPT) axis runs parallel to the HPA axis and is subject to the same autonomic and cortisol regulation; Hashimoto's thyroiditis involves intrathyroidal mast cells releasing histamine, TNF-α, and IL-6, and systemic immune modulation (NF-κB inhibition) together with HPA normalization via Mingmen (GV4)→lumbar sympathetic→adrenal can attenuate the autoimmune attack and restore TSH pulsatility; in Graves' disease, vagal dominance directly counters the sympathetic over-activity driving palpitations and anxiety. In migraine, mast-cell sensitization of the trigeminovascular system (cortical spreading depression → CGRP/SP/VIP → dural mast cells → histamine, PGE2) is amplified by the P2X3 axis; raised vagal tone (as in vagus-nerve stimulation), tryptase inhibition, the interictal vasodilation of Neidan HIF-1α→eNOS→NO, and Sirtuin-1→NF-κB inhibition each attenuate a node. In mood disorders, depression at the cellular level is chronic HPA over-drive (cortisol → hippocampal atrophy → BDNF suppression → reduced monoamines) combined with elevated neuroinflammation; the vagal arc (as effective as SSRIs), HPA normalization, BDNF up-regulation, inhibition of IL-6/TNF/NF-κB (lifting the IDO brake on serotonin synthesis), and Sirtuin-1→CREB→BDNF together correct this biology; for anxiety specifically, the insular activation produced when Neidan focuses yi on the dantian directly modulates the interoceptive cortex.

20.4 甲狀腺、偏頭痛與情緒障礙

在甲狀腺疾病中，下視丘—腦垂體—甲狀腺（HPT）軸與 HPA 軸平行受自律與皮質醇調節；橋本氏甲狀腺炎涉及甲狀腺內肥大細胞釋放組織胺、TNF-α、IL-6，而全身性免疫調節（NF-κB 抑制）與經命門（GV4）→腰交感→腎上腺的 HPA 正常化可減弱自體免疫攻擊並恢復 TSH 脈衝；對葛瑞夫茲氏病，迷走主導直接對抗驅動心悸與焦慮的交感過度活躍。在偏頭痛中，三叉神經血管系統的肥大細胞敏感化（CSD→CGRP / SP / VIP→硬腦膜肥大細胞→組織胺、PGE2）由 P2X3 軸放大；迷走張力上調（如迷走神經刺激術）、類胰蛋白酶抑制、內丹 HIF-1α→eNOS→NO 的發作間期血管舒張，以及 Sirtuin-1→NF-κB 抑制，逐一減弱各節點。在情緒障礙中，憂鬱在細胞層級為慢性 HPA 過度驅動（皮質醇→海馬萎縮→BDNF 抑制→單胺降低）合併神經發炎升高；迷走弧（與 SSRI 同等有效）、HPA 正常化、BDNF 上調、IL-6 / TNF / NF-κB 抑制（解除 IDO 對血清素合成的煞車）及 Sirtuin-1→CREB→BDNF，共同修正此生物學；就焦慮而言，內丹以意專注丹田時的腦島活化直接調節內感受皮質。

20.5 Arthritis, Gastrointestinal Disease, and Renal Disease

In arthritis, synovial mast cells release tryptase, TNF-α, IL-1β, and VEGF, with tryptase amplifying matrix-metalloproteinase (MMP) activity and cartilage destruction via PAR-2; the cholinergic anti-inflammatory pathway (α7nAChR, the same molecular target as vagus-nerve stimulation for rheumatoid arthritis), gentle movement that shifts synovial mast cells toward trophic output, and Sirtuin-1 attenuation of SASP all counteract this. In gastrointestinal disease, the gut contains the body's largest population of mucosal mast cells (IBS being essentially a mast-cell–afferent sensitization disorder); the visceral-massage pathway, α7nAChR stabilization, Neidan breath retention stimulating the enteric nervous system via Guanyuan (CV4)/Qihai (CV6), and HPA normalization that removes cortisol-driven mast-cell priming together modulate gut motility and the visceral-afferent threshold. In renal disease, chronic-kidney-disease progression is driven by glomerular hypertension (RAAS), tubulointerstitial inflammation

20.5 關節炎、胃腸道與腎臟疾病

在關節炎中，滑膜肥大細胞釋放類胰蛋白酶、TNF-α、IL-1β、VEGF，類胰蛋白酶經 PAR-2 放大基質金屬蛋白酶（MMP）活性與軟骨破壞；膽鹼能抗發炎通路（α7nAChR，與迷走神經刺激術治療類風濕性關節炎相同的分子標的）、溫和動作使滑膜肥大細胞轉向滋養性輸出，以及 Sirtuin-1 減弱 SASP，共同對抗。在胃腸道疾病中，腸道含人體最大的黏膜肥大細胞族群（腸躁症本質為肥大細胞—傳入神經敏感化）；內臟按摩路徑、α7nAChR 穩定、內丹閉氣經關元（CV4）/ 氣海（CV6）刺激腸神經系統，以及 HPA 正常化移除皮質醇驅動的肥大細胞預敏，共同調節腸道運動性與內臟傳入閾值。在腎臟疾病中，慢性腎臟病進展由腎絲球高壓（RAAS）、腎小管間質發炎

(mast-cell infiltration), and glomerular endothelial senescence (CGRP–mast-cell–SASP); vagal dominance suppressing RAAS (lowering renin and proteinuria), NF-κB/IL-6/TNF-α inhibition reducing interstitial fibrotic signalling, and Neidan HIF-1α→Sirtuin-1→eNOS→NO providing ischaemic-preconditioning-like endothelial protection each address a mechanism.

（肥大細胞浸潤）與腎絲球內皮衰老（CGRP–肥大細胞–SASP）驅動；迷走主導抑制 RAAS（降低腎素與蛋白尿）、NF-κB / IL-6 / TNF-α 抑制減少間質纖維化訊號，以及內丹 HIF-1α→Sirtuin-1→eNOS→NO 提供類似缺血預處理的內皮保護，逐一處理。

20.6 A Unified Disease Model | 20.6 統一疾病模型

These conditions are not separate diseases requiring separate mechanisms, but multiple phenotypic expressions of the same underlying dysregulation—excessive sympathetic tone, chronic low-grade mast-cell inflammatory activation, HPA over-drive, and NF-κB-driven gene expression. The mechanotransduction → Ca^{2+}/ATP cascade resets all four simultaneously through an integrated biological programme initiated at the acupoint-fascia interface; this is precisely why a single practice (20–40 minutes of slow movement and breathwork) can produce measurable improvements in blood pressure, blood glucose, inflammatory markers, mood, and pain at once. This is not polypharmacy under another name, but a recalibration of the autonomic–neuroimmune set-point at the cellular level.

這多種病症並非需要多種不同機制的獨立疾病，而是同一底層失調的多種表型表現——交感神經張力過高、慢性低度肥大細胞發炎激活、HPA 過度驅動、NF-κB 驅動的基因表達。機械轉導 → Ca^{2+}/ATP 級聯透過一個由穴位筋膜介面啟動的整合性生物程式，同時重置這全部四者；這正是為何單一練習（20–40 分鐘的緩慢動作與呼吸功法）能同時在血壓、血糖、發炎標記、情緒與疼痛上產生可測量改善。這不是以另一種名義進行的多重藥物療法，而是在細胞層級對自律—神經免疫設定點的重新校準。

21. Case Analysis (I): The Three-Level Mechanism and Treatment of Sciatica | 21. 個案分析（一）：坐骨神經痛的三層級機制與治療

Sciatica is not merely nerve compression but a multi-level neuroinflammatory disease. When a lumbar disc herniates (most commonly at L4/L5 or L5/S1), the nucleus pulposus is not only a mechanical compressor but a chemical irritant—nucleus-pulposus cells release TNF-α, IL-1β, IL-6, PGE2, and MMPs onto the nerve root, sensitizing nociceptors, lowering the firing threshold of the dorsal root ganglion (DRG), and triggering perineural mast-cell degranulation in a self-amplifying neuroinflammatory loop. Sciatica is therefore a three-level disease:

坐骨神經痛不僅是神經受壓，而是一種多層級的神經發炎疾病。當腰椎間盤突出（最常見於 L4/L5 或 L5/S1）時，髓核既是機械壓迫物，更是化學刺激物——髓核細胞將 TNF-α、IL-1β、IL-6、PGE2 與 MMP 釋放至神經根，使傷害感受器敏感化、降低背根神經節（DRG）放電閾值，並觸發神經周圍肥大細胞脫顆粒，形成自我放大的神經發炎迴路。據此，坐骨神經痛是一種三層級疾病：

Peripheral: nerve-root chemical irritation + perineural mast-cell activation	**周邊：神經根化學刺激 + 神經周圍肥大細胞活化**
↓	↓
DRG: ectopic firing + satellite-glia neuroinflammation	**DRG：異位放電 + 衛星膠細胞神經發炎**
↓	↓
	中樞：背角微膠細胞活化 + 中樞敏感化

Central: dorsal-horn microglial activation + central sensitization

Level one (peripheral): the vagal efferent arc delivers acetylcholine to the α7nAChR on perineural mast cells, inhibiting their NF-κB and blocking transcription of TNF-α/IL-1β/IL-6, thereby interrupting the perineural inflammatory amplification loop at its source. Stimulating Zusanli (ST36) relays via the paratrigeminal nucleus to the NTS and activates the dorsal motor nucleus of the vagus, producing a descending anti-inflammatory efferent signal.

Level two (DRG): ATP is dephosphorylated extracellularly to adenosine, which acts on A1 receptors on DRG neurons to hyperpolarize them, raise the firing threshold, and suppress ectopic firing; the Neidan breath-retention HIF-1α→BDNF axis acts on TrkB to inhibit the up-regulation of the sodium channels (Nav1.7, Nav1.8) that drive ectopic firing. Stimulation at Dazhui (GV14) and Mingmen (GV4) has been shown to up-regulate spinal BDNF and NT-3.

Level three (central): the ascending acupoint signal drives endorphin and enkephalin release via the periaqueductal gray (PAG)→rostral ventromedial medulla (RVM)→dorsal-horn circuit; Sirtuin-1 (activated via the Neidan HIF-1α cascade) specifically inhibits microglial NF-κB and the NLRP3 inflammasome, extinguishing the perpetuating neuroinflammation that maintains central sensitization.

Mingmen (GV4, at L2) lies precisely between the two most common herniation segments, and the "opening Mingmen" posture simultaneously provides axial decompression of the lumbar disc, trophic activation of the Mingmen connective tissue, and lumbar-sympathetic-ganglion modulation (improving nutrient delivery to the avascular disc). In addition, the psoas muscle originates from the L1–L5 vertebral bodies (immediately adjacent to the lumbar nerve roots and DRG), and the diaphragmatic breathing rhythm of Qigong produces a rhythmic length–tension cycle of the psoas through its respiratory attachment to the diaphragm's central tendon, progressively reducing chronic psoas tension—precisely the biomechanical mechanism behind the documented straight-leg-raise improvement (mean +9.4°).

層級一（周邊）：迷走神經傳出弧將乙醯膽鹼遞送至神經周圍肥大細胞的 α7nAChR，抑制其 NF-κB、阻斷 TNF-α / IL-1β / IL-6 轉錄，從源頭打斷發炎放大迴路。刺激足三里（ST36）經三叉旁核中繼至 NTS、活化迷走背側運動核，產生下行抗發炎傳出。

層級二（DRG）：ATP 經胞外去磷酸化為腺苷，作用於 DRG 神經元的 A1 受體使其過極化、提高放電閾值並抑制異位放電；內丹閉氣的 HIF-1α→BDNF 軸作用於 TrkB，抑制驅動異位放電的鈉離子通道（Nav1.7、Nav1.8）上調。於大椎（GV14）與命門（GV4）的刺激已被證明可上調脊髓 BDNF 與 NT-3。

層級三（中樞）：上行的穴位訊號經中腦導水管周圍灰質（PAG）→延髓頭端腹內側區（RVM）→背角迴路驅動腦內啡與腦啡肽釋放；Sirtuin-1（經內丹 HIF-1α 級聯）特異性抑制微膠細胞 NF-κB 與 NLRP3 發炎體，熄滅維持中樞敏感化的神經發炎延續機制。

命門（GV4，位於 L2）恰介於兩個最常見的突出節段之間，「開命門」姿勢同時提供腰椎間盤軸向減壓、命門結締組織的滋養性激活，以及腰交感神經節調節（改善無血管椎間盤的養分輸送）。此外，腰大肌起自 L1–L5 椎體（緊鄰腰神經根與 DRG），氣功的橫膈膜呼吸節律經腰大肌與橫膈膜中心腱的呼吸性附著產生節律性長度—張力循環，逐步降低慢性腰大肌張力——這正是直膝抬腿改善（平均 +9.4°）的生物力學機制。

Summary of Clinical Evidence | **臨床證據摘要**

Outcome measure 結果指標	Finding 發現	Source 來源
VAS pain reduction VAS 疼痛降低	SMD −0.55 (vs usual care); −1.07 across 8 chronic-low-back-pain RCTs SMD −0.55（對照常規照護）；8 項慢性下背痛 RCT 為 −1.07	PEDro 2024; Semantic Scholar PEDro 2024；Semantic Scholar
Straight-leg raise (SLR) 直膝抬腿（SLR）	+9.4° improvement vs usual care (p<0.001) 對照常規照護改善 +9.4°（p<0.001）	PEDro meta-analysis PEDro 統合分析
JOA functional score JOA 功能評分	Mean difference +4.40 vs usual care 對照常規照護平均差 +4.40	PEDro meta-analysis PEDro 統合分析
Zhineng Qigong, post-operative 智能氣功術後	Significant improvement in ODI, all SF-36 subscales, and EQ-5D ODI、所有 SF-36 次量表、EQ-5D 均顯著改善	BMC Musculoskeletal 2023 BMC Musculoskeletal 2023
Serum TNF-α 血清 TNF-α	Significantly reduced after acupoint + Qigong vs conventional therapy 穴位 + 氣功對照常規療法後顯著降低	PubMed LDH trial 2013 PubMed LDH 試驗 2013
ODI disability score ODI 失能評分	−8.14 points vs control at 16 weeks 16 週時較對照組降低 −8.14 分	NASS Journal 2024 NASS Journal 2024

The TNF-α reduction is especially significant: TNF-α at the nerve root is the single most important driver of sciatic-nerve inflammation, and the 2013 lumbar-disc-herniation trial directly measured its reduction correlating with clinical improvement—precisely the result of the cascade (mechanical stimulus →…→ vagus → α7nAChR → NF-κB/TNF-α) operating as charted. A three-level disease meets a three-level treatment, further complemented by the structural diaphragm–psoas–lumbar-disc decompression arc, making this approach more than a symptomatic analgesic—it carries potential disease-modifying action at the disc and nerve-root level.

TNF-α 降低尤其重要：神經根處的 TNF-α 是坐骨神經發炎最重要的單一驅動因素，2013 年的腰椎間盤突出試驗直接測量其降幅與臨床改善相關——這正是級聯（機械刺激 →…→ 迷走神經 → α7nAChR → NF-κB / TNF-α）精確運行的結果。三層級疾病遇上三層級治療，再輔以橫膈膜—腰大肌—腰椎間盤減壓弧的結構性補充，使此方法不僅是症狀性鎮痛劑，更在椎間盤與神經根層級具有潛在的疾病修飾作用。

22. Case Analysis (II): Eczema and Allergic Immune Disease | 22. 個案分析（二）：濕疹與過敏性免疫疾病

Eczema (atopic dermatitis) is essentially a disease of Th2 immune over-skewing and chronic low-grade inflammation, and its core mechanism can be strung into a cascade—within which the mast-cell and stress–cortisol biology discussed throughout this paper lies at the very centre.

濕疹（異位性皮膚炎）本質上是一種 Th2 免疫過度偏移及慢性低度發炎的疾病，其核心機制可串為一條級聯——而本文反覆論及的肥大細胞與壓力—皮質醇生物學，正位於此鏈條的核心。

Skin-barrier defect | **皮膚屏障功能缺損**

↓

Allergen and environmental-irritant penetration

↓

Th2 immune over-activation → release of IL-4, IL-13, IL-31

↓

Over-production of IgE antibodies

↓

Mast-cell and eosinophil activation

↓

Chronic skin inflammation, itch, rash

↓

過敏原及環境刺激物滲入

↓

Th2 免疫反應過度活躍 → IL-4、IL-13、IL-31 大量釋放

↓

IgE 抗體過度產生

↓

肥大細胞及嗜酸性粒細胞活化

↓

慢性皮膚發炎、瘙癢、皮疹

Stress aggravates both core problems—Th2 skewing and chronic inflammation—and Qigong mechanisms map onto each:

壓力會同時加劇 Th2 偏移與慢性發炎這兩個核心問題，而氣功機制可逐一對應：

Eczema pathological mechanism 濕疹的病理機制	**Counteracting action of Qigong** 氣功的對抗作用
Elevated cortisol aggravates inflammation 皮質醇升高加重發炎	Lowers cortisol output (down-regulates the HPA axis) 降低皮質醇輸出（下調 HPA 軸）
Th2 immune over-activation Th2 免疫過度活躍	Induces a Th2→Th1 shift, rebalancing the immune skew 誘導 Th2→Th1 免疫轉移，平衡免疫偏移
Elevated IL-6, TNF-α, IL-1β IL-6、TNF-α、IL-1β 升高	A 2026 meta-analysis shows significant reductions in IL-6 (−0.47) and IL-1β (−0.90) 2026 年統合分析顯示顯著降低 IL-6（−0.47）與 IL-1β（−0.90）
Insufficient anti-inflammatory IL-10 IL-10 抗發炎細胞因子不足	Significantly raises IL-10 (+0.87) 顯著提升 IL-10（+0.87）
Sympathetic over-activation 交感神經過度激活	Raises vagal tone, activates the parasympathetic system, and stabilizes cutaneous mast cells via α7nAChR 增強迷走神經張力、啟動副交感、α7nAChR 穩定皮膚肥大細胞
Chronic stress and poor sleep 慢性壓力與睡眠不足	Improves perceived stress (OR −0.60) and sleep quality (PSQI −2.47) 改善知覺壓力（OR −0.60）與睡眠品質（PSQI −2.47）

In terms of effect strength, Qigong has stronger RCT support for "reducing stress-induced skin flares" and "improving sleep quality" (★★★★☆), and moderate

就效果強度而言，氣功對「減輕壓力誘發的皮膚惡化」與「改善睡眠品質」有較強的 RCT 支持

support for "lowering systemic chronic inflammation," "rebalancing the Th1/Th2 skew," and "reducing scratching through emotion regulation" (★★★☆☆—the mechanism is clear but eczema-specific trials remain insufficient). Accordingly, Qigong cannot cure or replace drug treatment, but as a scientifically grounded, low-risk integrative adjunct—through stress reduction, lowered inflammation, improved sleep, and immune rebalancing—it is especially well suited as a natural complement to an existing pharmacological regimen (e.g. topical corticosteroids, leukotriene antagonists); its mechanism is highly consistent with the integrated mast-cell state of being "trophically active, immunologically quiescent" described in this paper.

（★★★★☆），對「降低全身性慢性發炎」「平衡 Th1 / Th2 偏移」「透過情緒調節減少搔抓」則為中等支持（★★★☆☆，機制清晰但濕疹專項直接試驗仍不足）。據此，氣功不能治癒或替代藥物治療，但作為一種有科學根據、低風險的輔助整合療法——透過減壓、降發炎、改善睡眠與平衡免疫——特別適合作為既有藥物方案（如外用類固醇、白三烯拮抗劑等）的自然補充；其機制與本文所述肥大細胞「滋養活躍、免疫靜息」的整合狀態高度一致。

23. An Illustrative Practice Method: White Ball Standing | 23. 修煉方法舉隅：白球站樁

The following is a static standing-post method (similar to Wuji standing) based on the Heidelberg Model of TCM—low-impact and suitable for all ages—offered as a concrete embodiment of this paper's mechanisms. The practice induces the sensation traditionally called the "qi sensation"—similar to the acupuncture "deqi"—by imagining holding a ball in front of the abdomen (the lower dantian); studies show that physiological activation typically appears within 2 minutes.

以下為一套依據海德堡中醫模型、低衝擊且適合各年齡層的靜態樁法（類似無極樁），可作為本文機制的具體實踐。練習中藉由想像在腹部前方（下丹田）抱球，誘發傳統上稱為「氣感」、類似針灸「得氣」的感覺；研究顯示生理活化通常在 2 分鐘內出現。

1. Basic neutral stance (not yet holding the ball): stand with feet parallel and shoulder-width apart, weight evenly distributed across the whole foot; knees softly bent, neither locked nor collapsing inward, aligned over the centre of each foot; gently tuck the pelvis so the tailbone sinks while the spine extends toward the crown; relax the chest into a slight hollow, shoulders away from the ears and sinking down; chin slightly in, eyes soft, breathing quietly through the nose.

1. 基本中立站姿（尚未持球）：雙腳平行、與肩同寬，體重均勻分布於整個腳掌；膝蓋微彎不鎖死、對齊腳掌中央；輕輕收攏骨盆使尾骨下沉，脊柱向頭頂延伸；放鬆胸部略呈含蓄、雙肩遠離耳朵下沉；下巴微收、雙眼柔和，以鼻安靜呼吸。

2. White ball at the lower dantian (abdomen): raise the arms in front of the lower abdomen as if embracing a large ball, hands at the level of the lower dantian (between the navel and the pubic bone), palms facing each other about a hand-span apart; elbows lower than the wrists and slightly outward so the armpits feel open; imagine a light, buoyant white ball filling the space between the hands and the abdomen, with awareness resting in this region.

2. 白球置於下丹田（腹部）：雙臂抬至下腹前方環抱大球，雙手位於下丹田高度（肚臍與恥骨之間），掌心相對、相距約一掌寬；手肘低於手腕並略向外，使腋下開展；想像一個輕盈有浮力的白球充滿雙手與腹部之間的空間，覺察停留於此區域。

3. White ball at the middle dantian (chest): raise the arms so the ball sits in front of the centre of the chest, at heart height, palms facing each other and fingers softly curved; keep the shoulders sunk and the trapezius relaxed, elbows in a gentle arc and lower than the

3. 白球置於中丹田（胸部）：抬高雙臂使球位於胸部中央、心臟高度前方，掌心相對、手指柔和環抱；保

wrists; feel the space between the hands and the chest as a rounded, expanding field of energy.

4. White ball at the upper dantian (forehead / third eye): slowly raise the arms so the ball is held in front of the forehead or the brow, maintaining the rounded shape, palms facing each other; keep the neck long and the chin slightly in, the effort of holding the arms coming from the body's centre and the legs rather than from shrugging; let awareness rest in the region between the hands and the centre of the head.

5. Closing: slowly lower the arms, placing one palm over the other at the lower abdomen (below the navel), maintaining the relaxed stance and breathing quietly, feeling warmth settle in the lower abdomen; after one or two minutes let the arms hang at the sides, gently roll the shoulders, and walk a few relaxed steps before moving on to other activity.

持雙肩下沉、斜方肌放鬆，手肘略呈圓弧並低於手腕；感受雙手與胸部之間如一個圓潤擴張的能量場。

4. 白球置於上丹田（前額／第三眼）：緩緩抬臂使球托持於前額或眉心前方，維持圓弧形狀、掌心相對；保持頸部修長、下巴微收，托舉力量來自身體中心與雙腿而非聳肩；覺察停留於雙手與頭部中央之間。

5. 收功：緩緩放下雙臂，一掌疊於另一掌置於下腹（肚臍下方），維持放鬆站姿安靜呼吸，感受溫熱沉降於下腹；一至兩分鐘後讓雙臂垂於身側，輕轉肩膀、放鬆走幾步後再進行其他活動。

24. Integration: A Multi-Scale Cascade Model of Qigong and Neidan | 24. 整合：氣功與內丹的多尺度級聯模型

The evidence reviewed supports a multi-scale, bidirectional model in which Qigong movement and Neidan internal work activate overlapping but distinct cascades, both converging on the mast cell as a core cellular transducer. The model operates at four scales:

所回顧的證據支持一個多尺度、雙向模型，其中氣功動作與內丹內修激活相互交疊但各具特色的級聯，兩者均匯聚於肥大細胞這一核心細胞轉換器。該模型在四個尺度上運作：

Scale 尺度	Qigong mechanism (common to all practice) 氣功機制（所有修煉共通）	Additional Neidan mechanism 內丹額外機制
1 Mechanical / hypoxic 1 機械 / 缺氧	Slow movement → fascial mechanotransduction → Piezo1/2 → Ca^{2+} → acupoint mast-cell degranulation 緩慢動作 → 筋膜力學傳導 → Piezo1/2 → Ca^{2+} → 穴位肥大細胞脫顆粒	Breath retention → transient hypoxia → HIF-1α stabilization in mast cells → trophic degranulation; rising CO_2 → vasodilation → thermal activation of Piezo1; yi (intention) → cortico-autonomic projection → mast-cell efferent modulation 閉氣 → 短暫缺氧 → 肥大細胞中 HIF-1α 穩定 → 滋養性脫顆粒；CO_2 升高 → 血管擴張 → Piezo1 熱激活；意 → 皮質—自律投射 → 肥大細胞傳出調節
2 Neural 2 神經	Acupoint afferents → hypothalamus (HPA regulation, CRH inhibition) + vagal nuclei (raised vagal tone, α7nAChR mast-cell stabilization) 穴位傳入 → 下視丘（HPA 調節、CRH 抑制）+ 迷走神經核（迷走張力升高、α7nAChR 肥大細胞穩定）	Upper-dantian / GV20 attention → prefrontal–hypothalamic feedback → direct HPA inhibition; GV4 Mingmen attention → lumbar sympathetic modulation → reduced adrenal-cortical output 上丹田 / GV20 注意 → 前額葉—下視丘反饋 → 直接 HPA 抑制；GV4 命門注意 → 腰交感調節 → 腎上腺皮質輸出降低
3 Neuroendocrine–immune 3 神經內分泌—免疫	Lower cortisol + higher vagal tone → fewer pro-inflammatory cytokines (IL-6, TNF-α, IL-1, IL-8, IL-17), more anti-inflammatory (IL-10, IFN-γ), NF-κB inhibition 皮質醇降低 + 迷走張力升高 → 促發炎細胞因子減少（IL-6、TNF-α、IL-1、IL-8、IL-17），抗發炎增加（IL-10、IFN-γ），NF-κB 抑制	HIF-1α → Sirtuin-1 → NF-κB deacetylation → SASP attenuation; Sirtuin-1 → eNOS → NO → endothelial protection HIF-1α → Sirtuin-1 → NF-κB 去乙醯化 → SASP 衰減；Sirtuin-1 → eNOS → NO → 內皮保護
4 Genomic / molecular 4 基因組 / 分子	Lower cortisol + oxidative stress → telomerase up-regulation, telomere protection; SOD/GPX up-regulation → less oxidative damage; SASP attenuation → less inflammaging 皮質醇 + 氧化壓力降低 → 端粒酶上調、端粒保護；SOD / GPX 上調 → 氧化損傷減少；SASP 衰減 → 炎性衰老降低	HIF-1α → PGC-1α → mitochondrial biogenesis; Sirtuin-1 → TERT deacetylation → telomerase activation; intermittent hypoxia → hormetic anti-ageing gene expression HIF-1α → PGC-1α → 線粒體生物合成；Sirtuin-1 → TERT 去乙醯化 → 端粒酶激活；間歇性缺氧 → 激素興奮型抗衰老基因表達

Within this framework, the mast cell is not a passive responder to physical stimulus but a cellular integrator standing at the intersection of the ancient Neidan tradition and contemporary molecular gerontology: a sensor of mechanical force, oxygen tension, temperature, and neuropeptidergic signals, whose calibrated response to the practitioner's breath, movement, and intention determines the biological age of the tissue it inhabits. The ancient Daoist wisdom of cultivating qi through Neidan to reach longevity is finding its most precise empirical expression in the language of HIF-1α, Sirtuin-1, and mast-cell trophic biology.

在這一框架中，肥大細胞不僅是物理刺激的被動反應者，而是站在古老內丹傳統與當代分子老年學交叉點上的細胞整合者：它是機械力、氧分壓、溫度及神經肽能信號的感測器，其對修煉者呼吸、動作及意念的校準響應，決定了其所居組織的生物年齡。道家通過內丹培育氣以通往長壽的古老智慧，正在 HIF-1α、Sirtuin-1 及肥大細胞滋養生物學的語言中找到其最精確的實證表述。

25. Clinical Implications and Practice Design

The evidence reviewed supports a tiered approach to Qigong-based anti-ageing and adjunctive treatment:

1. **Tier one—general Qigong (movement-based):** Wu Qin Xi and Baduanjin have the strongest RCT evidence base for reducing oxidative stress and improving anti-ageing biomarkers. The minimum effective dose is roughly 3–5 sessions per week for at least 2–4 months to achieve telomerase and HRV effects.
2. **Tier two—Neidan-oriented practice (inward, breath-focused):** advanced practitioners with experience in dantian cultivation and breath regulation, through extreme respiratory slowing (1–2 cycles per minute) or structured breath retention, access the additional HIF-1α→Sirtuin-1 anti-ageing cascade and deeper vagal–mast-cell stabilization. The Neidan transition from "deliberate action" (you wei) to "effortless action" (wu wei) corresponds at the cellular level to a shift from mechanotransduction-driven mast-cell activation to intention-driven vagal mast-cell stabilization.
3. **Tier three—precision Qigong (personalized prescription):** selecting specific forms based on individual meridian-conductance profile, inflammatory biomarkers, and HRV: those with high baseline inflammation and low vagal tone are preferentially prescribed slow-breathing Neidan practice to maximize parasympathetic/α7nAChR mast-cell stabilization; those with high oxidative stress and mitochondrial dysfunction are preferentially

25. 臨床含義與修煉設計

所回顧的證據支持基於氣功的抗衰老與輔助治療之分層方法：

1. **第一層——一般氣功（動作為主）：**五禽戲與八段錦具有最強的氧化壓力降低與抗衰老生物標記 RCT 證據基礎。最低有效劑量約為每週 3–5 次、至少 2–4 個月，以達到端粒酶與 HRV 效應。
2. **第二層——內丹導向修煉（內修、呼吸為重）：**具丹田培育與調息經驗的高階修煉者，通過極度呼吸放緩（每分鐘 1–2 個週期）或結構性閉氣，接觸額外的 HIF-1α→Sirtuin-1 抗衰老級聯及更深度的迷走神經—肥大細胞穩定化。從「有為」到「無為」的轉變，在細胞層級對應從力學傳導驅動的肥大細胞激活，轉向意念驅動的迷走神經肥大細胞穩定。
3. **第三層——精準氣功（個性化處方）：**基於個人經絡電導率譜、發炎生物標記與 HRV 測量選擇特定形式：基線發炎高、迷走張力低者，優先推薦緩慢呼吸的內丹修煉以最大化副交感 / α7nAChR 肥大細胞穩定；氧化壓力高、線粒體功能障礙者，優先推薦閉氣修煉以最大化 HIF-1α→PGC-1α 線粒體生物合成。

prescribed breath-retention practice to maximize HIF-1α→PGC-1α mitochondrial biogenesis.

As for the recommended "dose" for general health, practice should occur 3–4 times per week for 40–60 minutes over at least 12 weeks (specific conditions such as depression may require more than 24 weeks), while a single session can provide acute relief of stress and anxiety. The mast-cell biology described in this paper also suggests particular clinical relevance for conditions characterized by mast-cell over-activation: atopic dermatitis, mast-cell activation syndrome (MCAS), fibromyalgia, irritable bowel syndrome, and chronic fatigue syndrome. Both practices have no significant adverse effects, require no equipment, can be adapted to mobility limitations, and produce simultaneous benefits across cognitive, cardiovascular, musculoskeletal, immune, and genomic domains, making them well suited to integration with conventional anti-ageing and preventive-medicine programmes (no serious adverse events have been reported in major systematic reviews; a minority of beginners, about 24%, experience mild muscle soreness).

就一般健康的建議「劑量」而言，宜每週 3–4 次、每次 40–60 分鐘、持續至少 12 週（憂鬱症等特定疾病可能需 24 週以上），而單次練習即可提供急性的壓力與焦慮緩解。本文所述肥大細胞生物學亦提示，這些修煉在以肥大細胞過度激活為特徵的病症中具有特別的臨床相關性：特應性皮炎、肥大細胞激活症候群（MCAS）、纖維肌痛、腸躁症與慢性疲勞症候群。兩種修煉方式均無顯著不良效應、無設備需求、可適應行動能力限制，並同時在認知、心血管、肌肉骨骼、免疫及基因組領域產生效益，因而非常適合與傳統抗衰老及預防醫學計劃整合（主要系統性回顧中未報告嚴重不良事件；少數初學者約 24% 會出現輕微肌肉酸痛）。

26. Limitations and Future Research Directions

Although the evidence is growing, several methodological limitations warrant caution:

- **Heterogeneity of interventions:** Qigong encompasses dozens of forms, and Neidan encompasses multiple schools (Quanzhen, Zhengyi, Wudang) with differing breath-retention protocols and orbit sequences; most studies investigate a single form, limiting generalizability.
- **Difficulty of blinding:** no convincing placebo exists, and most evidence relies on active-control or waiting-list designs, with widespread variation in study quality and high heterogeneity.
- **Scarcity of human mechanistic studies:** most acupoint mast-cell response data come from animal models; in human subjects, the mast-cell degranulation profile during Neidan breath retention and the HIF-1α transcriptional activity at dantian acupoints have not been directly measured.
- **Many applied mechanisms remain hypothetical:** some of the molecular cascades described in Parts II–IV (particularly the disease-specific and anti-ageing pathways) are mechanistic

26. 局限性與未來研究方向

儘管證據漸增，仍須審慎看待若干方法學局限：

- **干預的異質性：**氣功涵蓋數十種形式，內丹涵蓋多個流派（全真、正一、武當）並具不同的閉氣方案與周天序列；多數研究僅調查單一形式，限制了可推廣性。
- **設盲困難：**不存在令人信服的安慰劑，多數證據依賴積極對照或等待名單對照設計，並普遍存在研究品質參差與高異質性。
- **人類機制研究的缺乏：**多數穴位肥大細胞反應數據來自動物模型；在人類受試者中，內丹閉氣期間肥大細胞脫顆粒譜與丹田穴位 HIF-1α 轉錄活性的直接測量尚未進行。
- **應用機制多屬假說：**第二至四部所述的部分分子級聯（特別是疾病特異性與抗衰老路徑）為機制性假說與跨領域推論，尚非已確立的臨床共識。

hypotheses and cross-disciplinary inferences, not yet established clinical consensus.

Priority research directions include: RCTs comparing general Qigong with Neidan-style breath-retention practice on a validated anti-ageing panel (telomere length, plasma CGRP, serum 8-OHdG, Sirtuin-1 activity, HRV SDNN) with long-term follow-up (≥12 months); direct measurement of HIF-1α mRNA and protein in peripheral blood mononuclear cells immediately after structured breath retention in experienced Neidan practitioners; histological studies comparing mast-cell density and mediator profiles at dantian acupoints (CV4, CV6, GV4) in Neidan practitioners versus age-matched controls; investigation of the primo vascular system as a conduit for the propagation of mast-cell mediators during microcosmic-orbit practice; and precision-Neidan trials matching breath-retention protocols to individual meridian-conductance and inflammatory-biomarker panels. Rigorous sham-controlled trials are still needed to disentangle specific effects.

優先研究方向包括：以驗證的抗衰老面板（端粒長度、血漿 CGRP、血清 8-OHdG、Sirtuin-1 活性、HRV SDNN）並長期隨訪（≥12 個月）的 RCT，比較一般氣功與內丹式閉氣修煉；在有經驗的內丹修煉者中，於結構性閉氣後立即直接測量外周血單核細胞的 HIF-1α mRNA 與蛋白質；比較內丹修煉者與年齡匹配對照者丹田穴位（CV4、CV6、GV4）的肥大細胞密度與介質譜的組織學研究；研究原始血管系統作為小周天期間肥大細胞介質傳播通道的功能；以及以個人經絡電導率與發炎生物標記面板匹配閉氣方案的精準內丹試驗。此外，仍需嚴謹的假對照試驗以釐清特異性效應。

27. Conclusion | 27. 結論

Qigong and Neidan practice activate a coherent multi-scale cascade of physiological mechanisms that together constitute a profound mind-body regulation and a potential anti-ageing intervention, operating through two overlapping but complementary modes. The first mode—shared by all Qigong practice—applies mechanotransductive stimulation to acupoints along meridian trajectories, activating mast cells whose degranulation products bridge the gap between somatic movement and neural, immune, and endocrine signalling; through the afferent arcs activated at acupoints, Qigong modulates the autonomic nervous system (increasing HRV and vagal tone), the HPA axis (lowering cortisol), and the immune system (lowering pro-inflammatory cytokines and NF-κB). These systemic effects converge on the cellular and molecular determinants of biological ageing and translate clinically into measurable improvements in stress, anxiety, sleep, fatigue, pain, and a range of chronic diseases.

氣功與內丹修煉激活了一套連貫的多尺度生理機制級聯，共同構成深刻的身心調節與潛在的抗衰老干預，並通過兩種相互交疊但互補的模式運作。第一種模式——由所有氣功修煉共享——對沿經絡走行的穴位施加力學傳導刺激，激活肥大細胞，其脫顆粒產物彌合了軀體動作與神經、免疫及內分泌信號傳導之間的鴻溝；通過穴位激活的傳入弧，氣功調節自律神經（增加 HRV 與迷走張力）、HPA 軸（降低皮質醇）及免疫系統（降低促發炎細胞因子與 NF-κB），這些系統性效應匯聚於生物衰老的細胞與分子決定因素，並在臨床上轉化為對壓力、焦慮、睡眠、疲勞、疼痛與多種慢性病的可測量改善。

The second mode—specific to Neidan—adds an entirely distinct cellular language via the HIF-1α signalling axis. Breath retention delivers controlled, intermittent hypoxic pulses to mast cells at anatomically designated dantian and acupoint locations, triggering trophic HIF-1α-mediated mast-cell activation (releasing VEGF, TGF-β, NGF, and calibrated amounts of histamine) that maintains acupoint tissue integrity; the CO_2-driven

第二種模式——特有於內丹——通過 HIF-1α 信號軸增加了一種截然不同的細胞語言。閉氣向解剖學指定的丹田與穴位輸送受控的間歇性缺氧脈衝，觸發滋養性 HIF-1α 介導的肥大細胞激活（釋放 VEGF、TGF-β、NGF 及校準量的組織胺），維持穴位組織完整性；CO_2 驅動的血管擴張產生沿小周天的溫熱「氣感」之

vasodilation produces the warm, pulsatile progression of the "qi sensation" along the microcosmic orbit; and the HIF-1α→Sirtuin-1 cascade thus activated acts at the genomic level to stimulate mitochondrial biogenesis, activate telomerase via TERT deacetylation, inhibit NF-κB and SASP, and protect endothelial cells from the CGRP–mast-cell axis that drives skin ageing. Intentional focus (yi) on specific dantian and acupoints (particularly GV4 Mingmen and GV20 Baihui) provides a top-down cortico-autonomic complement to these bottom-up hypoxic signals, constituting the cellular substrate of "guiding qi with intention." Within this unified framework—from the ancient cultivation of the dantian to telomerase and mast-cell trophic biology—traditional Neidan wisdom and contemporary molecular science find a coherent dialogue at the meeting point of "the mast cell as core transducer." A final emphasis is warranted: the value of these practices lies in their role as low-risk integrative methods complementary to conventional medicine, not as a replacement for treatment of any disease.

搏動性進展；由此激活的 HIF-1α→Sirtuin-1 級聯在基因組水平刺激線粒體生物合成、經 TERT 去乙醯化激活端粒酶、抑制 NF-κB 與 SASP，並保護內皮細胞免於驅動皮膚衰老的 CGRP—肥大細胞軸。對特定丹田與穴位的意念專注（特別是 GV4 命門與 GV20 百會）為這些自下而上的缺氧信號提供自上而下的皮質—自律補充，構成「以意導氣」的細胞基底。在這一統一框架中，從古老的丹田培育到端粒酶與肥大細胞滋養生物學，傳統內丹智慧與當代分子科學在「肥大細胞作為核心轉換器」這一交會點上獲得了連貫的對話。最終須強調：這些修煉的價值在於作為與常規醫療互補的、低風險的整合性方法，而非任何疾病的替代療法。

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法；部分分子與疾病特異性機制屬機制性假說，尚待更嚴謹的人體研究證實。任何具體的治療、用藥或練習計畫，應由合格的醫療專業人員評估後決定。