Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *Meditation*

The subtle body: an interoceptive map of central nervous system function and meditative mind–brain–body integration

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Meditation research has begun to clarify the brain effects and mechanisms of contemplative practices while generating a range of typologies and explanatory models to guide further study. This comparative review explores a neglected area relevant to current research: the validity of a traditional central nervous system (CNS) model that coevolved with the practices most studied today and that provides the first comprehensive neural-based typology and mechanistic framework of contemplative practices. The subtle body model, popularly known as the chakra system from Indian yoga, was and is used as a map of CNS function in traditional Indian and Tibetan medicine, neuropsychiatry, and neuropsychology. The study presented here, based on the Nalanda tradition, shows that the subtle body model can be cross-referenced with modern CNS maps and challenges modern brain maps with its embodied network model of CNS function. It also challenges meditation research by: (1) presenting a more rigorous, neural-based typology of contemplative practices; (2) offering a more refined and complete network model of the mechanisms of contemplative practices; and (3) serving as an embodied, interoceptive neurofeedback aid that is more user friendly and complete than current teaching aids for clinical and practical applications of contemplative practice.

Keywords: subtle body; neurofeedback; meditation; mindfulness; yoga; contemplative neuroscience

Background

Meditation research is of interest to different disciplines and communities. One of the aims of the Advances in Meditation Research (AMR) conference is to approach this interdisciplinary field in ways that encourage participants to look beyond their usual silos toward mutually enriching dialogue. As a scholar of the Indic contemplative tradition and a clinical researcher in neuropsychiatry, I have sought a middle way between our modern disjunction of mind-from-matter basic neuroscience and practical application. For this paper (stemming from the AMR conference), I have chosen a topic unusual to professionals on both ends of the academic spectrum, despite its relevance to clinicians and its interest to the public.

Given the popularization of yoga, most are now familiar with the yogic model of the body–mind's central regulating system, called the subtle body (*sūkṣma-śarīra*) and widely known as the chakra system. While most see this as a guide for yoga practice, traditional scholar–practitioners understand it as a scientific map of central nervous system (CNS) function.[1–4] Even if this premise is true, as I have proposed elsewhere,[4,5] the question remains: Why should this ancient Indian model be of current interest to researchers, clinicians, and the public, rather than being relegated to the province of Indologists?

Over the years, my work has yielded three provisional answers to this question: (1) given the relevance of meditation research, there is a need for a clear and comprehensive map of contemplative practices,[6–8] and the subtle body may prove more useful than current maps, because it categorizes contemplative practices not on the basis of phenomenological or procedural factors but on underlying neural mechanisms.[4] (2) Given the brain's complexity, current efforts to make sense of the explosion of

doi: 10.1111/nyas.13065

data in neuroscience must grapple with determining the appropriate level of reduction versus integration for any particular study or application.[2,9] The subtle body model offers a viable alternative to reductive, brain-centric approaches to CNS function and takes recent network models[9,10] to the next level: embodied neurofunctional mapping. (3) Given the range of practical applications of mindfulness and related techniques, there is a growing demand for clear and user-friendly formats for explaining, teaching, and deepening contemplative practices.[7] The subtle body model offers a time-tested paradigm for such applications, one that has the advantages of being systematic and integrative, while also offering a user-friendly map for interoceptive neurofeedback to help guide contemplative practice.

Approach

The interdisciplinary approach I chose to explore the potential for using the subtle body map as a tool in meditation research combines the methods of Indic scholarship with the findings of contemporary neuropsychology. I first propose a general model of the map and its key elements, then compare that detailed model with current network models of the CNS, with special reference to models of the types, mechanisms, and uses of meditation.

While the earliest references to the subtle body in Indian literature are found in the Upanishads (600–300 BCE), the first systematic descriptions appear later (300 BCE–400 CE), in the classical formulations of the Ayurvedic medical and Yogic contemplative traditions.[11] Gradually, these references led to more elaborate descriptions devised for expert traditions of neuropsychology (*tantrayāna*) and neuropsychiatry (*rasāyana*) (developed 400–1200 CE). Both systems were integrated by India's institutions of academic psychology and medicine, including the world's first university and medical school at Nalanda (450–1250 CE).[12,13] The main sources for this study are drawn from the Nalanda tradition, as refined over the centuries (650–1950 CE) in the Buddhist Monastic Colleges of North India and Tibet.[2,3,14] The model of the subtle body that follows is not meant as a final depiction of any one traditional map, much less of the totality of the countless such maps used in different times and traditions. It is offered as a composite model, for heuristic purposes, to support the presentation of the interdisciplinary perspective that this paper is meant to provide.

On the neuroscience side, I have surveyed the mounting evidence on the brain effects of meditative practices and reviewed emerging models proposed by Davidson and Lutz,[15] Vago and Silbersweig,[16,17] Travis and Shear,[18] Brewer,[19,20] and Siegel.[21]

Comparing and correlating two CNS models

Indic subtle body model of neural structure and function

As the name "subtle body" suggests, the traditional model is explicitly meant as a map not of the gross anatomical structure of the nervous system, but rather of its "subtle material" (*sūkṣmarūpa*) structure and function.[11] Its structure is seen as a natural part of the body's intrauterine development, described as recapitulating the evolution of life in 10 stages, from primitive invertebrates to higher mammals.[22] The material structure of the nervous system is seen as molecular (*māhābautika*) and develops with the embryo along a central channel (*avadhūti*), analogous to the neural tube. It is understood as composed of the coordinated development of four basic elements: two structural and two functional. The structural elements are called channels or reeds (*nadī*) and hubs or complexes (*cakra*); the functional elements are energies or winds (*prāṇa*, *vāyu*) and drops or fluids (*bindu*, *ojas*).[23] In some contexts, a third functional element is added, metabolic heat or fire (*tejas*, *agni*).[11] In this model, mental and physical elements interact through bimodal causation at the interface of mind states with energy patterns. In top-down causation, mental processes direct the dynamic flow of energies and drops and, with repetitive flow, these in turn alter the plastic structure of channels and hubs. For instance, worst-case thinking and reactive emotions, such as fear, trigger the flow of energy–drops in the polar side channels that support aggressive and avoidant somatic reactions, reinforcing reactive structural patterns that restrict the flow of bliss energy–drops through the reward circuits of the central channel.[24] In bottom-up causation, physiological processes effect changes in states of consciousness and also influence the sensory–emotional factors and symbolic contents of mind. For instance, unhealthy dietary intake, poor lifestyle habits, and social–emotional stress can influence

wake–sleep cycles, promote reactivity and insomnia, and contribute to mental conditions such as anxiety or depression.[1,2,25,26]

The subtle body is described as having a threefold structure. Although familiar images focus on its three axial channels and seven hubs, more complete models detail three main levels of structure and function: gross (*audarika, sthūla*), subtle (*sūkṣma*), and extremely subtle (*susūkṣma*).[23,27] These levels overlap with the five layers or sheaths (*kośas*) described in the Samkhya-Yoga tradition and the neuropsychology of the Hindu Tantras.[11] The coarse level of the subtle body consists of an extensive network of peripheral channels that branch out in complex circuits from hubs along the central channel. These peripheral channels support gross sensorimotor and physiological processes, such as the functioning of the external senses, proprioception, locomotion, and the internal organs of the cardiorespiratory, metabolic, immunologic, and genitourinary systems. This network, aligned with waking-state consciousness, is structured like an arterial tree, with a number of primary channels that issue directly from the central channel at one of seven hubs along the neuraxis. It overlaps with the nutritive layer (*annamaya-kośa*) in the yoga system.

The subtle level of the subtle body is depicted in the Hatha Yoga map. This level is organized around a central channel aligned with the neuraxis: starting from a point just behind the forehead, curving up along the midline toward the crown, then bending back down following the arc of the skull in the shape of an umbrella handle until it parallels the brainstem and spinal cord, ending at the genitals. This axis is punctuated at seven points by hubs, where the circuits that branch out to serve the peripheral network of the coarse level emerge.[23] And it is also entwined by two polar side channels that begin at the nostrils and follow the central channel all the way to the genital region, winding around it and switching laterality at each of the hub points until they branch out in the pelvis to end at the anus and urethra (according to the Buddhist Kalachakra Tantra).[22] This subtle structural level supports internal mental processing—offline reflection, memory and fantasy, daydreaming, and dreaming—and is structured as a central processing network for the whole subtle body. It also forms the biological basis for the integrative functions of learning, self-regulation, motivation, and internal reward, as well as for the lateral and vertical integration of neural networks and processes throughout the body–mind. This level overlaps with the mental and energetic layers of the yoga system (*prāṇa-mano-maya-kośa*).

Finally, the extremely subtle level of the subtle body is nested within the central channel and constitutes the biomolecular source and regulatory center of the 10 primary energies and eight primary drops that operate within all of its channels, hubs, and networks. The 10 energies include five that regulate basic bodily functions—inspiratory/circulatory, expiratory/expressive, somatosensory/locomotor, digestive/metabolic, and excretory/reproductive—plus five that modulate the five senses. The eight drops include four pairs of arousing (masculine) and calming (feminine) vital fluids that together modulate the four main levels and states of consciousness—waking, dreaming, sleeping, and orgasmic. Although primarily located within the central channel at the level of the heart hub, where cardiorespiratory rhythms, internal reward, and primal consciousness are regulated, the extremely subtle level is intimately linked with the biomolecular processes regulated from the six other hubs within the central channel.[11] Its status as a biomolecular source is clear from the fact that the extremely subtle body is structurally identified not with the central channel or heart hub per se, but with the extremely subtle "indestructible" drop (*akṣara-bindu*), whose main seat is in the heart hub.[23,24] This drop not only feeds the secondary drops based in the six other axial hubs, but communicates with the genetic "seeds" (*bījas*) born of the fused maternal and paternal genetic material from the egg and sperm.[23,26] And it supports the extremely subtle energy and deep-sleep mind, also known as the life-giving energy of pure bliss (*sukha-śūnya*) and the death-like mind of clear light (*prabhāsvara*).[28] This level overlaps with the bliss and consciousness layers of the yoga system (*ānanda-vijñāna-maya-kośa*).

Within this triune structure, the aspects of the subtle body most relevant to our study lie at the subtle level, where coarse, peripheral mind–body processes interface with the central organizing structures, and these interface in turn with the biomolecular sources of conscious and vegetative self-regulation at the extremely subtle level. This dual interface is best described by mapping the three main channels and seven main hubs that constitute the subtle level, and then mapping the basic

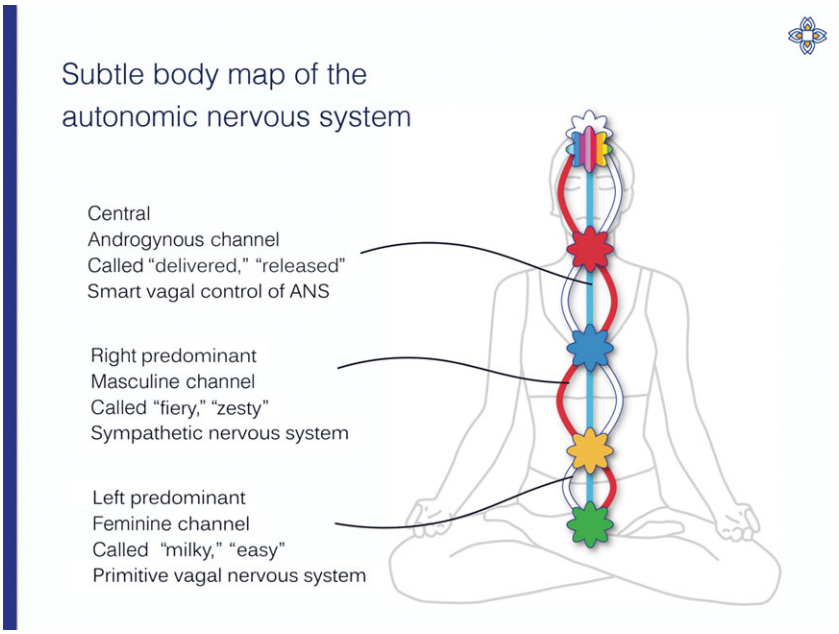

Figure 1. **The three main channels of the subtle body.**

functional elements of the primary energies and drops onto them.

The two reed-like side channels begin at their respective nostrils, join the thicker, stalk-like central channel where it starts at the forehead hub, entwining around it there and at each of the next five hubs, and then separating from it in the pelvic region. The left, described as milky (*idā*) or easy (*lalanā*), is said to be whitish in tone, to carry lunar energies and feminine drops, and to end at the anus (Fig. 1). The right, described as fiery (*piṅgala*) or zesty (*rasanā*), is said to be reddish in tone, to support solar energies and masculine drops, and to end at the urethra. The central channel, described as delivered (*suśumnā*) or released (*avadhūti*), is said to be bluish in tone, to support blissful energies and androgynous drops, and to end at the tip of the male or female sex organ.[23,a] The polar energies and drops that flow within the two side channels are said to maintain balance between levels of arousal and rest, attraction and aversion, and lateral functions such as nostril dominance, as well as to support the oscillations involved in menstrual, diurnal, and ultradian rhythms, from menstruation and wake–sleep cycles, to metabolic and cardiorespiratory oscillations.

As for the main hubs (Fig. 2), each is located at a specific point along the central channel, has a distinctive structure fleshed out by the number and arrangement of its spokes or petals, and supports a range of specific functions based on the dynamic elements of specific energies and drops. Although the main hubs are mapped somewhat differently by different traditions and practice systems, a broad consensus prevails. Here, I follow the optimal integral process (*anuttara-yoga-tantra*) system developed by Buddhist scholar–practitioners at Nalanda

[a]The qualities attributed to the side channels vary in different systems. The gender association is usually reversed in the Buddhist Tantras: the red, right, solar channel is typically identified as feminine, and the left, lunar channel as masculine, in line with the natural color of menses and semen, as well as the feminist transvaluation of gender symbols in the Mahayana tradition (sun = ultimate, wisdom, feminine; moon = relative, compassion, masculine). According to some traditions, the color and gender quality of the channels are reversed in males and females, with the lunar, masculine channel on the right in women, and vice versa. This relativity is to be expected given the general consensus that the lateral dominance, and even the laterality of the channels themselves, changes at various points within the subtle body and at various times according to a range of natural cycles.

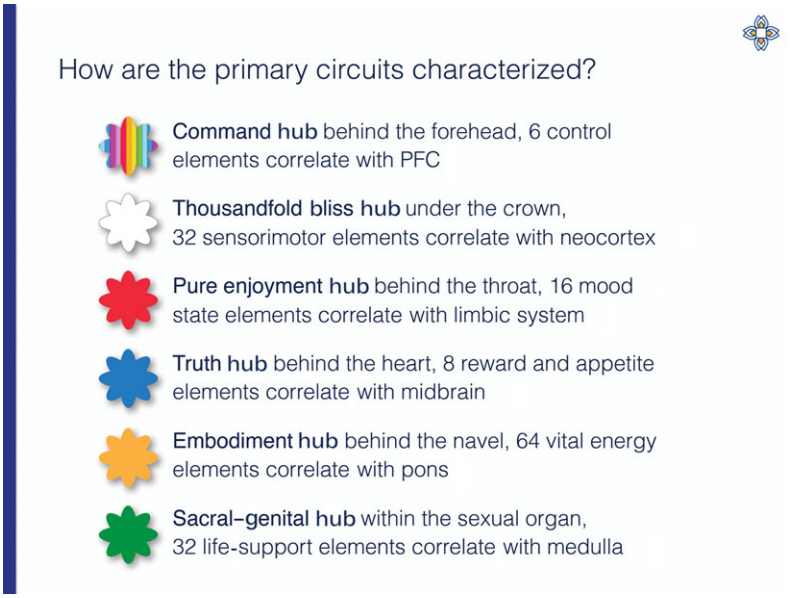

Figure 2. **The six main hubs of the subtle body with proposed brain correlates.**

University, in dialogue with scholar-adepts of the Shaivite Yoga Tantra traditions of Kashmir, and accepted by all schools of Tibetan Tantric psychology and practice.[3,14,28–30]

The first hub, called the command hub (*ajñā-cakra*), is located at the rostral end of the central channel, just behind the forehead, where it is entwined once by each of the two polar side channels that begin at the nostrils and rise up to meet it. It is said to have six main spokes that radiate out from the hub and curve back caudally, like the spokes of an umbrella. It is one of the bases for the subtle, central forms of vital energy (*prāṇa-vāyu*) and pure white, masculine waking drops, thought to support the waking state, higher intelligence, conscience, and self-regulation.

The second hub, referred to as the thousandfold great bliss hub (*māhāsukha-cakra*; yoga system: *sahasra*), is located at the crown, where it is entwined by each of the two polar side channels. It is said to have 32 spokes that radiate outward and downward, like a skull-cap, some connecting with the upper spokes of the command hub. It is the basis for coarse, peripheral vital energy, including its five derivative sensory forms, along with their off-white masculine orgasmic drops. These are said to support the daydream and orgasmic states, intentional motor actions, symbolic constructs of self and world, and the functioning of the five sense faculties.

The third hub, referred to as the pure enjoyment hub (*viśuddhi-cakra*), is located at the level of the larynx, where the central channel curves downward toward the brainstem and is entwined once by the two polar side channels. It is said to have 16 main spokes that radiate rostrally upward, connecting with the caudal spokes of the great bliss hub and the ventral spokes of the command hub. It is the base for the expressive energy (*udāna-vāyu*) and the pink masculine dreaming drops, said to support the dream state, and the functions of speech, imagination, emotion, and energy balance.

The fourth hub, called the primal truth hub (*dharma-cakra*, yoga: *anāhata*), is located at the level of the heart, where it is triply entwined by the polar side channels. It is said to have eight spokes that radiate downward, like the spokes of an umbrella. It is the basis for the pervasive energy (*vyāna-vāyu*), for the subtle and extremely subtle forms of vital energy, as well as for the hot pink androgynous sleep drops. It is said to support wake–sleep regulation, cardiorespiratory rhythms, motivational instincts, primal awareness, and the core bliss system.

The fifth hub, referred to as the embodiment hub (*nirmāṇa-cakra*, yoga: *maṇipura*), is located just below the navel, where it is entwined once by

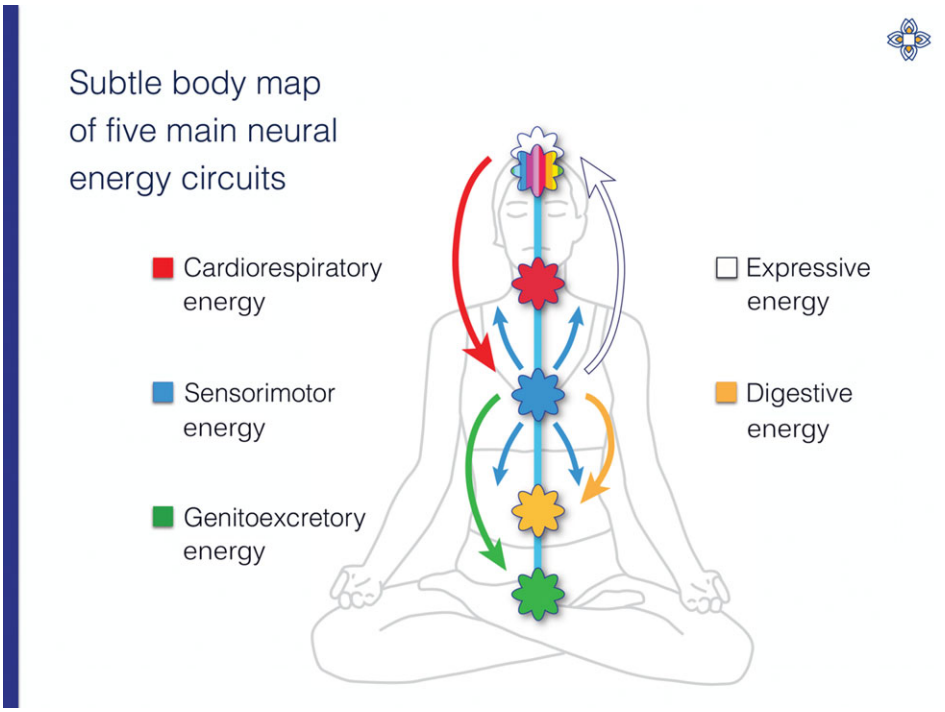

Figure 3. The main wind energies of the subtle body.

each of the polar side channels. It is said to have 64 spokes that radiate upward like an upended umbrella, some connecting with the descending spokes of the primal truth hub. It is the base for the equalizing energy (*samāna-vāyu*) and vermillion feminine waking drops, thought to support the waking state, digestion and metabolism, visceral sensation, and respiratory rhythms.

The sixth and seventh hubs, called the sacral–genital hub (*guyha-ratnagra-cakra*, yoga: *svādhiṣṭhāna-mūladhāra*), are a complex of two hubs (in some maps, three hubs), with one located in the sacrum at the root of the genitals and another at the tip of the clitoris or penis. The sacral hub is entwined once by each of the polar side channels, before they separate from the central channel to end at the anus and urethra. The sacral hub is thought to have 32 spokes that radiate out and downward like the spokes of an umbrella, and the genital hub is said to have 16 spokes that radiate out and upward like an upended umbrella, connecting with some of the spokes from the sacral hub. They are the bases for the evacuative energy (*apāna-vāyu*) and the deep red feminine dream, sleep, and orgasmic drops, thought to support dreaming, deep sleep, and orgasmic states, elimination, sexual function, assimilation, and homeostasis (Figs. 3 and 4).[b]

Modern research on neural structure and function

The first modern models of the CNS were based on gross anatomy, with early attempts to map brain wiring and localize function aided by tissue-staining histology, electroencephalography (EEG), and neurosurgical correlation. Converging studies of memory, learning, development, and

[b]In addition to these seven main hubs, with their respective spokes, energies, and drops, the subtle body model in some systems also distinguishes a range of secondary structural and functional elements. These include up to seven more secondary hubs along the central channel and up to seven more hubs in the lower extremities; secondary, tertiary, quaternary, quinary branchings of primary spokes, yielding a much expanded network; up to 108 aspects of the five basic and five derivative energies, or even more when these 108 are further subdivided by micro-oscillations over the course of each day; and a multiplication of each of the main drops, as they distribute through the many channels of that expanded network.

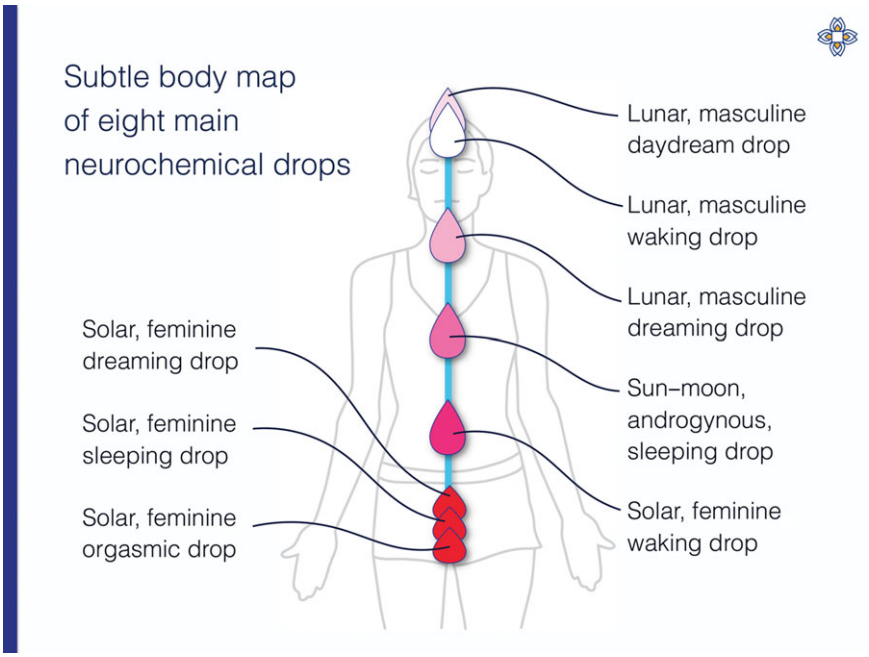

Figure 4. **The main biochemical drops of the subtle body.**

recovery in the 1990s led to a shift in paradigm away from hard wiring and localization to models based on plasticity and connectivity. Computational EEG and functional brain scanning have accelerated this trend. The development of polyvagal theory, neuroendocrinology, neuroimmunology, and epigenetics has further decentralized our understanding of the complex embodied functions of the nervous system. In reviewing current advances from this broad perspective, a number of areas of relevance to this study emerged.

The model of the brain as a triune evolutionary heterarchy,[31] in which three nested levels of neural structure support external cognition and social action, internal social–emotional processing, and embodied self-regulation, bears some resemblance to the threefold model of the subtle body. Crucial breakthroughs in self-regulation offer another analogue to the regulatory structure and function of the main channels and hubs that make up the subtle level of the subtle body. The key regulatory role of midline structures, such as the medial prefrontal cortex, corpus callosum, cingulate cortex, midbrain, and brainstem, is consistent with the model of self-regulatory structures in the subtle body, organized around midline channels and the hubs that intersect with them (Fig. 5).

Further, the latest science on the autonomic nervous system[32] suggests analogies between current thinking on autonomic self-regulation and the central self-regulatory structure and function of the subtle body. Beyond the obvious analogy between the polar regulatory functions of the side channels and the sympathetic and parasympathetic aspects of the autonomic system, there are several key elements of polyvagal theory that suggest correlations with the subtle body model. First, our growing understanding of the role of the myelinated vagus in voluntary breathing seems to correlate with the depiction of the side channels as starting at the nostrils.[11,33] Second, current findings of the lateral asymmetry in vagal versus sympathetic functional dominance seem to correlate with the depiction of the two side channels as polar structures that show lateral functionality: the left, lunar channel correlated with the calming, nurturing function of the vagal system; and the right, solar channel with the arousing, activating function of the sympathetic system.[6,34] The finding that the lateral dominance between the two systems undergoes routine shifts following ultradian rhythms may be correlated with the way the side channels cross the midline at each hub, as well as the traditional observation that the lateral dominance of the two channels changes in

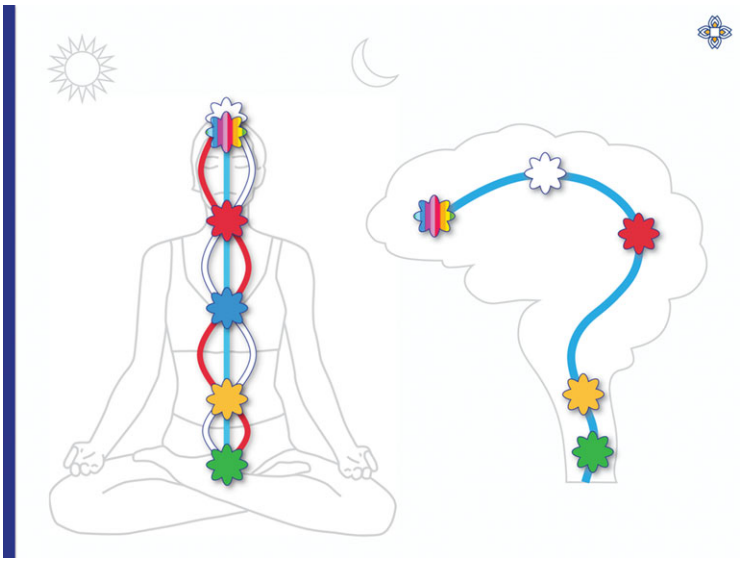

Figure 5. **The main hubs cross-referenced with correlated brain structures.**

rhythmic cycles, some as short as quarter hours and others lasting lunar months.[34,35] Finally, the finding that the distribution of the two vagal nerves and nuclei bisect the body at the heart, with the smart vagus serving the upper body and the old vagus serving the lower, may correlate with the depiction of the nodal role of the heart hub as the complex where the two side channels wrap around the central channel three times each, as opposed to just once.[23] In some systems, the laterality and functionality of the channels switches entirely at the level of the heart,[22,24] further supporting a polyvagal correlation.[11]

In what follows, I suggest correlations between the main hubs of the subtle body and the main levels of brain structure and function. Although the vertical alignment of the hubs along the central channel broadly corresponds with the vertical alignment of neuroanatomical structures along the neuraxis, their correspondence becomes less evident as we move from rostral to caudal. Simply put, while the hubs are stretched over the whole neuraxis from the forebrain to the sacrum, the levels of neural structure and function recognized by modern science are condensed into the rostral portion of the neuraxis from the forebrain to the brainstem. This divergence precludes any simple correspondence between hubs and levels, and forces a choice between one of two cross-mapping strategies. The common strategy is anatomical: linking the first two hubs with the prefrontal cortex and neocortex, while linking the third through seventh hubs with autonomic structures, such as the esophageal, aortic, hypogastric, and pelvic plexuses. The novel strategy that I propose is functional: linking all seven hubs with distinct central regulating networks that have implicit correspondences with the brain structures that support them, but explicit locations mapped onto brain–body structures that provide the conscious mind with palpable interoceptive feedback about central neural states and processes.

Recent breakthroughs in meditation research have focused on our growing understanding of the prefrontal cortex, especially its key role in higher cognitive, executive, and social self-regulatory capacities, which have led to it being considered the conductor of neural integration and the central control hub of the brain's cortical networks.[21,36] The start of the central channel at the command hub behind the forehead is suggestive of the key role played by the prefrontal cortex in conscious self-regulation and neural integration. The number and orientation of its spokes—six elements interfacing caudally with the great bliss and enjoyment hubs—are consistent with the moderate complexity and interface with the neocortex and limbic system. This suggestion gains weight when comparing the functions attributed to that hub—higher intelligence, executive function, conscience, and

emotional regulation—with those of the various regions of the prefrontal cortex (Fig. S1 in Supporting Information).

There have also been recent gains in our understanding of the neocortex, including the description of the mirror neuron empathy network for reading facial expressions and body language;[37,38] the discovery of the default mode network (DMN), found to generate default self-referential narrative and self-imagery loops during off-task processing;[39,40] and the delineation of the insula's role in adding interoceptive input to the monitoring and representation of the body.[41] These new findings appear to correlate with the structure and function of the great bliss hub. Its location at the crown is consistent with that of the neocortex, and the orientation and number of its spokes—32 elements interfacing ventrally with the command and pure enjoyment hubs—are consistent with the orientation and number of neocortical areas and their intimate links with the prefrontal cortex and limbic system. There appears to be functional correspondence given the depiction of the crown hub as supporting constructive perception, creation of body images of self and other, the initiation of bodily action, and the mind state of daydreams and fantasy (Fig. 2S in Supporting Information).

There have also been gains in our understanding of the limbic system with respect to the role of the anterior cingulate in integrating emotion with its behavioral expression;[42] the role of the posterior cingulate in integrating memory and self-reference;[43] the interplay of the amygdala and hippocampus in weighing emotional salience in light of personal history and social context;[44] the role of the striatum in implicit learning and reinforcement;[45] and the hypothalamic regulation of autonomic tone and endocrine balance in light of primary mood states.[46] Current science on the limbic system may be correlated with the structure and function of the pure enjoyment hub. Although its location at the level of the throat does not map anatomically onto the limbic brain, the cranial nerves to that region (V–XII) do support conscious motor control and sensory feedback for social behaviors—sharing food, emotions, information, memories, and fantasies—which set the stage for the limbic processing of emotional information. In addition, the number and orientation of the spokes of the enjoyment hub—16 elements interfacing upward with the bliss and command hubs—are consistent with the moderate complexity and two-way interface of the limbic system with the neocortex and prefrontal cortex. There appears to be a correlation between limbic functions as described in the current literature and the functions attributed to the enjoyment hub: emotional communication and expression, supporting imagination and the dream state, and maintaining subtle mind/body energy balance (Fig. 3S in Supporting Information).

There have also been recent refinements to our understanding of the main functions of the midbrain, which include regulation of arousal and sleep cycles in concert with other brainstem nuclei, governed by a hypothalamic switch;[47] modulation of motivation, internal reward, and the reinforcement of action patterns by the basal ganglia;[48] and the integration of complex autonomic responses, including cardiorespiratory rhythms.[49] These findings appear to overlap with depictions of the truth hub. Although its location at the level of the heart does not map anatomically onto the midbrain, the mixed vagal and sympathetic innervation to the region not only regulates moment-to-moment cardiorespiratory rate and rhythm but also provides higher consciousness with what may be the most palpable and sensitive feedback indicators of the central level of activation/contentment, pain/pleasure, and expectation/reward, mainly mediated by neural processing in the midbrain. The number and orientation of the spokes of the truth hub—eight elements interfacing downward with the emanation hub—are consistent with the minimal complexity of the midbrain as well as its close linkage with deeper brainstem structures. There also appears to be some correlation between the functions of the midbrain as described in the current literature and those attributed to the truth hub, including the reinforcement of appetite, motivation, and conditioning; the generation of waking awareness and wake–sleep cycles; maintaining cardiorespiratory rhythms; and the affective experience of pleasure, bliss, and happiness (Fig. 4S in Supporting Information).

Current findings have also clarified the functions of key pontine nuclei and pathways, which include imposing a higher-order regulation on medullary cardiorespiratory rhythms;[50] supporting waking awareness and rapid eye movement sleep with key pontine cholinergic and adrenergic

Table 1. Hubs, winds, drops, and their functions compared with brain structure and chemistry

Pure enjoyment	16 elements Rostral links	Expressive/ male dreaming	Imagination Emotion	Limbic cortex	Serotonin Dopamine
Primal truth	8 elements Caudal links	Pervasive/ male/female sleep	Reward activation	Subcortical midbrain	Dopamine Opioids
Emanation	64 elements Rostral links	Digestive/ fem. waking	Metabolism Vital rhythms	Pontine brainstem	Serotonin Acetylcholine
Sacral genital	32 elements Internal links	Genitourinary/female Sleep–orgasm	Reproduction Elimination	Medulla oblongata	Oxytocin Vasopressin

nuclei;[51] initiating digestion via cranial nerves originating in pontine nuclei;[52] noxinergic support of heart, gut, and sexual organ perfusion;[53] and facilitating the fine planning and execution of mental and physical acts by acting as a relay in corticocerebellar association networks.[54] These findings suggest that the pons may be correlated with the emanation hub. Although its location just below the navel does not map anatomically onto the pons, the primitive vagal and sympathetic innervation to the gut, linked with extensive serotonergic and noradrenergic neurons and cholinergic myocytes, not only regulates the balance of digestion versus retention, somatic relaxation versus arousal, and quiescent versus expansive mood, but also provides higher consciousness with what may be its most palpable and sensitive feedback indicators of the central level of wake–sleep arousal, metabolic activation, and mood regulation, largely mediated by serotonin, norepinephrine, and acetylcholine produced centrally in the pons. The number and orientation of the spokes of the emanation hub—64 elements interfacing upward with the truth hub—are consistent with the complexity of the pontine brainstem and its close linkage with the midbrain. There may also be some correlation of pontine functions with those attributed to the emanation hub, including supporting high arousal states in waking and dreaming, regulating cardiorespiratory rhythms, and initiating and supporting digestion (Fig. 5S in Supporting Information).

Finally, research has refined our understanding of the primary functions of the medulla, including support of deep slow-wave sleep and orgasm states;[55,56] regulation of vital cardiorespiratory rhythms and reflexes, including the vagal heart brake;[57] maintenance of gastrointestinal secretion and motility;[58] and fostering the mixed autonomic activity of sexual arousal and response.[59] These findings suggest that the medulla may be correlated with the sacral–genital hub. Although its location on the central channel from the sacral to the genital levels does not map anatomically onto the medulla, the complex mix of primitive vagal and sympathetic innervation to the pelvis not only regulates the organs of excretion and reproduction, but also provides higher consciousness with what may be its most palpable and sensitive indicators of the central level of deep somatic relaxation, metabolic resilience, and sexual responsiveness, largely mediated by the autonomic tone maintained by the medulla. The number and orientation of the spokes of the sacral and genital hubs—32 elements facing downward and 16 upward, respectively, interfacing with one another—are consistent with the complexity of the medullary brainstem as well as its relative autonomy as a homeostatic center (Table 1). There also appears to be a correlation between the functions of the medulla as described in the current literature and those attributed to the sacral–genital hub: supporting the deepest states of consciousness, deep sleep, and orgasm; regulating basic cardiorespiratory rhythms; supporting digestion; and fostering sexual response (Fig. 6S in Supporting Information).

Modern models of the types and mechanisms of meditation

Since the early explorations in the field,[60,61] researchers have proposed a range of models of the types and mechanisms of meditation. As attention moved from Benson's initial work on the relaxation response to the work of the next generation focused on mindfulness, proponents of mindfulness sought to distinguish the two methods. Davidson and Goleman distinguished practices such as the relaxation response and transcendental meditation (TM) from mindfulness and related practices by defining the former as narrow focused and the latter as open focused.[62] As Davidson and

Lutz began working more closely with Tibetan scholar–practitioners, this simple typology gave way to the current consensus model on the basis of a traditional threefold distinction: focused attention (FA), open monitoring (OM), and nonreferential compassion (NRC), which they condensed into two by categorizing NRC as a special case of OM.[15] Travis and Shear have modified this consensus model to include self-transcendence as an autonomous third category, which they associate with expertise.[18] Others have modified it by including nondual awareness as an autonomous third category.[63] Alongside this phenomenological model, three explanatory models have come to the fore, which all reframe Deikman's insight that the common mode of action underlying contemplative states is deautomatization.[64] The observation that contemplative practices share conscious self-regulation as a common mode of action is a unifying theme in explanatory schemas as diverse as Tang's Qigong-based model of meditation as a practice of mind/body integration,[65] Brewer's network model of meditation as overriding default self-referential activity,[19] and Vago's mindfulness-based model of meditation as an integrative mind–brain practice that leads from self-awareness to self-regulation and culminates in self-transcendence (SART).[17]

Mechanistically, a consensus model has slowly evolved and began by expanding Benson's autonomic model of meditation as eliciting a parasympathetic relaxation response. Early mindfulness studies framed meditation as a mix of stress reduction and learning, mediated by the combined exercise of relaxation and attention.[66] In a previously published review,[6] I linked this hybrid model to basic research on allostasis and neural plasticity, proposing that the calming function of meditation improves allostasis by reducing the stress response, while its attentional function enriches learning by stimulating use-dependent plasticity. Later studies on the effects of meditation further supported the mechanistic link between attention and neuroplasticity, by associating it with EEG patterns and structural changes consistent with increased activation, myelination, and neurogenesis.[67–70] Initially, the findings supporting this model focused on the role of the prefrontal cortex and related structures, such as the insula, where increased cortical thickness and connectivity were presumed to reflect the growth of integrative capacity caused by mindfulness practice.[68,71] The neural network model proposed by Vago shows how mindfulness builds conscious self-regulation of cortical processing, by enhancing activation of the frontoparietal control network.[16] Brewer's network model of mindfulness proposes that practice helps integrate cortical processing by enhancing prefrontal regulation of the DMN.[20]

More recently, this neocortical model has been challenged by studies showing that meditative practices increase the size of integrative structures and the function of integrative networks at limbic, subcortical, and brainstem levels of the nervous system. For instance, mindfulness increases hippocampal volume[68,69,72] and activation of the thalamus and midbrain,[73,74] compassion training increases activation of the nucleus accumbens and ventral tegmental area,[75–77] recitation increases hypothalamic volume,[78] and nondual awareness increases medullary gray matter.[79] Although prefrontal regions seem to modulate such deep changes, these findings stretch the consensus model toward a more inclusive framework of vertical integration under prefrontal influence. The consensus model has been further stretched by findings that meditation may work by fostering lateral integration of structures that show lateral specialization or dominance.[35,80–82] Finally, the effects of recitation and breath-control practices on autonomic centers in the hypothalamus and brainstem have underscored recent work on the vagus,[57] reintroducing the key role of autonomic regulation within an expanded model of how meditation promotes vertical and lateral integration of the nervous system.

Indic subtle body map of the mechanisms and effects of meditation

The subtle body map was accepted by classical Indian science as the definitive map of the embodied mind and nervous system early in the Common Era. It supports a neuropsychological approach to meditation and its effects quite unlike the procedural typologies and mechanistic models adopted by modern researchers. Not only does the traditional model offer a more comprehensive typology of practices, but it also links them and their effects to the structure and function of the subtle body. Specifically, it maps four to six main types of contemplative practice onto particular subtle body structures and processes, and provides mechanistic explanations of

how each practice affects underlying structures and processes.

Among the different systems of mapping contemplative practices and effects onto the subtle body, the variance reflects minor distinctions in terminology or procedure rather than major differences. I will illustrate this model using the system of optimal integral process practice in the Indo-Tibetan *Kālachakra* or Wheel of Time tradition.[22,c] In this system, contemplative practice is described as a continuum of progressive methods of self-regulation and integration, involving six main types of practice: (1) withdrawal (*pratyāhāra*) involves calming and clearing the mind using methods of open internal focus, similar to OM practices such as mindfulness;[83,84] (2) contemplation (*dhyāna*) involves focusing attention on specific objects, such as images, affirmations, or mind itself, akin to FA practices such as concentration or compassion training;[85,86] (3) recitative breath control (*prāṇāyāma*) involves balancing and mixing the polar energies of the nervous system, using rhythmic exercises of mental recitation and mindful breath-control, such as Mantra Yoga or Kundalini Yoga;[78,87] (4) retention (*dhāraṇā*) involves fusing polar energies in states of absorption that activate the chemistry of internal reward, using practices such as Tummo (*candalī*) or Ananda Marga that mix imagery, recitation, and breath holding;[88,89] (5) sublimation (*anusmṛti*) involves eliciting euphoric flow states that activate the chemistry of sexual arousal and consummation, using practices such as Tibetan Tantra that mix erotic imagery and breath holding;[90] (6) integration (*samādhi*) involves integrating the ecstatic states accessed through sublimation into all mind/body processes, using non-dual awareness–compassion practices, such Zazen, Advaita, advanced TM Siddhi, Dzogchen, or Mahamudra.[79,91]

As for mapping these practices and their mechanisms, this model explains that all mental activity both depends on and directs the flow of energy and drops within specific channels and hubs of the subtle body. With repeated practice, top-down mental activity shapes the subtle material structure and function of the channels and drops that it interacts with, because the dynamic flow of energy and drops alters the patterns of molecular matter that shape the plastic structure of the subtle body. Within this framework, the six types of contemplative practice are mapped onto different levels and regions of the subtle body, reinforcing integrative structures and self-regulating functions throughout. Specifically, the more advanced the practice, the deeper it moves toward the extremely subtle core level of the subtle body and the further down the rostral–caudal axis of the central channel. Of note, advancement in practice is mapped differently from the resultant progress toward integration, and both forms of progression are mapped differently by different systems and traditions. For instance, Hindu systems tend to map progress toward integration as vertical movement toward the crown, while Buddhist systems tend to map progress as a complex path that begins with top-down access, proceeds through bottom-up regulation, and culminates in centralized integration at the heart.[d]

According to the Wheel of Time tradition, withdrawal practices, such as mindfulness, are mapped onto the rostral end of the central channel, at the command hub just behind the forehead. Mechanistically, their effect is said to be withdrawing

[c]This system is of interest for several reasons. First, it is the most syncretic of the Buddhist Tantras, drawing on the Shaivite and Vaishnavite systems within the Hindu Yoga Tantra tradition, as well as on the two main systems of Buddhist Yoga Tantra. Second, it is the most modern, scientific version of India's integral process practice of contemplation, known for its "transparent" (Tib. *shin-tu gsel-ba*) science-based approach to the esoteric traditions of Indic neuropsychology, neuropsychiatry, and medicine.

[d]The precise mapping of various practices and stages of practice onto different subtle body structures and processes varies among different traditions, systems, and lineages. Hindu systems tend to map progress vertically toward the crown, and Buddhist systems more often map it centrally toward the heart. Confusion also arises from the fact that different systems emphasize practices that access different hubs; for example, Kashmiri Shaivite Tantra and Buddhist Mother Tantra emphasize practices at the navel and crown; Kālachakra Tantra emphasizes practice at the forehead, navel, and crown; and Buddhist Father Tantra emphasizes practice at the genital hub. These different points of access to regulation and integration of the subtle body, however, are not to be confused with the final destination of practice: the fully integrated state of the nervous system.

Table 2. Practice types, substrates, and effects compared with brain structure and findings

Practice	Substrate	Mechanism	Effect	Structure	Findings
Withdrawal mindfulness	Command hub Coarse NS	Calm energy Lateral balance	Mindfulness Mood balance	Prefrontal cortex	Self-regulation Neurogenesis
Reflective focus	Bliss hub Subtle NS	Energy focus Subtle balance	Quiescence Compassion	Sensorimotor neocortex	Self-aware More empathy
Breath-work recitation	Pure joy hub Core channel	Energy control Core access	Absorption Bliss	Limbic cortex	More proactive Reinforcement
Retention breath-locks	Truth hub ES NS	Fused energy Bliss drops	Immersion Great bliss	Subcortical midbrain	ANS balance Bliss reward
Sublimation sex energy	Emanation ES heart drop	Stilled energy Bliss flow	Equipoise Orgasmic bliss	Pontine brainstem	Mixed arousal Smart vagus
Integrative awareness	Genital hub Entire CNS	Integral energy Pervasive bliss	Integration Altruistic bliss	Medulla oblongata	Epigenetics Neurogenesis

NS, nervous system; ANS, autonomic nervous system; CNS, central nervous system; ES, extremely subtle.

energy and awareness from the peripheral, coarse body–mind into the central, subtle body–mind, as well as balancing polar masculine and feminine energies within the side channels. Contemplation practices, such as compassion training, mantra recitation, visualization, or concentrative quiescence, are mapped onto the great bliss hub at the crown. They are thought to work by concentrating energy and awareness more fully into the subtle body–mind and by further balancing the polar energies within the side channels. Recitation and/or imagery conjoined with rhythmic breathing practices, such as Tibetan Tantra or Kundalini Yoga, are mapped onto the pure enjoyment hub at the throat, correlated here with the limbic system. They are thought to work by mixing and fusing the polar energies of the side channels to the point where they can access the central channel network of subtle bliss energy and drops. Retention practices, such as Tibetan Tummo, are linked with the primal truth hub at the heart, correlated here with the midbrain, and are thought to work by immersing the fused polar energies of the side channels into the central channel, where their retention activates the male and female bliss drops that originate there. Sublimation practices, such as the conjoined yogas of erotic archetype imagery (*jñānamudrā*) and advanced breath control (*candalī*), are mapped onto the emanation hub at the navel, correlated here with the pons. They are said to work by increasing the retention and immersion of the fused polar energies into the extremely subtle bliss energies and drops within the central channel, to the point where the release and flow of those energies and drops can be consciously regulated and mastered. Finally, integration practices, such as nondual awareness–unconditional compassion, are mapped onto the sacral–genital hub at the pelvis, correlated here with the medulla. They are thought to work by gradually integrating the mastery of the extremely subtle bliss energies and drops from the core network of the central channel with all levels of the subtle and coarse body–mind, to the point at which the entire mind–body process is irreversibly committed to positive social engagement in all forms of cognition, emotion, and action (Table 2).

Challenging questions for future research

Obviously, comparing two maps and models of meditation as divergent as the subtle body and brain map is an exercise in which findings must be carefully considered. Yet, however preliminary its findings, this inquiry suggests some compelling correlations and raises some challenging questions for meditation research.

The first correlation of this comparison may be the most surprising. Modern neuropsychology is not the first scientific tradition in history to propose a model of the human mind as embodied within and dependent on a CNS. It is not the first to map that nervous system as a network of structural and dynamic elements including pathways, complexes, energies, and chemical drops. It is not the first to map that system into a triune heterarchy of levels that develop from an embryonic neural tube and organize themselves along the neuraxis in structural–functional networks that show both lateral and vertical specialization. Nor is it the first to

explain the workings of the mind—at all levels and in all forms—as effects of the natural causality at work in the CNS.

The second correlation is equally surprising: modern neuropsychology is not the first scientific tradition in history to recognize that mental activity, such as the exercise of attention, can have a top-down influence on the workings of the CNS: from altering the dynamics of neural energy and chemistry, to reshaping the structural elements of neural networks and circuits. Given these facts, perhaps the third correlation should not be as surprising as it is. The general mechanism of meditation proposed by this tradition—a cascade of top-down effects leading from mindful attention to neural energy shifts, from energy shifts to chemical modulation, from chemical modulation to structural alterations in neural networks and hubs—in qualitative broad strokes clearly anticipates the outline of models proposed by modern researchers.

Given these correlations, a clear case can be made for comparing current models of meditation with traditional models based on the subtle body. The case grows stronger when attention is more closely paid to how the subtle body map can be cross-referenced with brain maps, including refinements emerging from current research. But the strongest argument for scrutiny of this model stems from the fact that the practices most studied today—mindfulness, yoga, compassion training, recitation, visualization, breath control, objectless compassion, and nondual awareness—were developed within the Indic tradition on the basis of that model. This makes it likely that some body of observational data and mechanistic understanding regarding them has been incorporated into the model. At a minimum, it would seem to make sense for modern researchers to consider the neural typology of contemplative practices mapped onto the subtle body. The next sensible step would be to cross-examine the data from modern studies of Indic practices against that model. Finally, given its practical utility over time and across cultures, it is reasonable to assume that the traditional model or some current version of it may be helpful as an aid for understanding and teaching contemplative practices, especially to the lay public.

Assuming that researchers can recognize the subtle body as an embodied network map of the CNS and accept it as a model that may be scientifically valid despite its provenance, what would challenge those interested in studying it as practically relevant to their work? The main challenge is to the modern research preference for objective observation, quantitative methods, and mechanical measures.[2,3,92] The methodology assumed by the subtle body map diverges significantly from each of these. The observing stance from which the Indic map was made is introspective and intersubjective (first and second person) rather than strictly objective (third person and impersonal). While its verbal formulas are precise, and there is quantification of some variables (the complexity of neural structures and the length of breath patterns), its analytic method is qualitative rather than quantitative. Finally, the model itself is not dependent on or linked to mechanical instruments, but is based on the imaginative mapping of neural structures and processes, embedded within the inner landscape of embodied imagery, sound and breath exercises, and validated by the interoceptive metrics of bodily sensations and neural afferent feedbacks.[e]

This challenge is relevant to the most promising application of the subtle body model—as an interoceptive neurofeedback map for introducing and deepening contemplative practice. As expected given modern methodological bias, the trend in meditation research has been toward the development of technological biofeedback aids, from laboratory functional magnetic resonance imaging and portable EEG devices, to personal autonomic monitors, such as Fitbit and Jawbone. This is only natural, given the technological bent and industrial imperatives of today; however, from the traditional vantage point, these aids are of questionable value. Of course, high-tech neural measures have been indispensable

[e] A similar methodological hurdle comes up in modern medicine and psychiatry. Taking a thorough history and carefully attending to patient narratives is known to dramatically improve the accuracy of differential diagnosis while building rapport for treatment. Yet modern medical practice is rapidly moving away from these qualitative methods, toward costly diagnostic technologies and often misleading laboratory tests. Likewise, conventional psychotherapy is thought be as effective, more preventive, less risky, and better tolerated than psychopharmacology, yet it is often dismissed as ineffective or unscientific because it relies on interpersonal dialogue rather than pharmaceutical agents or statistical measures.

for establishing and advancing the field of meditation research. But outside the laboratory, when it comes to mastering, applying, and teaching meditation techniques, such aids risk being not only redundant, but also misleading. In such contexts, the cost–benefit equation that makes the traditional methodology seem limited relative to modern empirical methods actually flips, with its seeming limits figuring as strengths. While technical aids draw attention outward to the device and add mechanical biofeedback as a surrogate for specific neural processes, the subtle body model draws attention inward—supporting the reflexive turn of meditation—and uses the body's own sensory feedbacks as interoceptive cues and reinforcers of those neural processes.

In this light, the subtle body emerges as the more appropriate technology for these applications, where the externalized technology of high-tech biofeedback devices and monitors in comparison seems extraneous and confounding. Of course, there may always be some individuals for whom the familiarity and technological appeal of external biofeedback aids serves as the meditative equivalent of training wheels in the unfamiliar challenge of learning to direct attention internally. But when it comes to teaching aids for introducing and deepening contemplative practice for most people in most contexts, a good case can be made for the superiority of an interoceptive map, such as the subtle body, over modern brain-based models.[f]

[f] If the subtle body model were to catalyze breakthroughs in meditation research, this would not be unprecedented, or even exceptional, in the history of science. Modern linguistics and Medeleev's periodic table are both attributed to the West's first encounters with the Sanskrit grammar of Pāṇini (c.550 BCE).[93,94] Pāṇini based the world's most complete observational grammar and most rigorous semiotics on a table of phonemic elements that categorizes speech sounds—vowels and consonants—by descriptively mapping them onto their physical substrate: the multivariate mechanics of sound set up when breath, produced in one of five vibrational modes and baffled at one of five anatomical nodes, is forced through the human vocal apparatus. The same embodied perspective is responsible for the approach to mind and contemplation taken by his rough contemporaries, Shakyamuni and Pātañjali, as expressed in the subtle body. The West's recent adoption of Indic contemplative science and practice is only one more instance of the general East–West transmission of science and technology described by postmodern historians of science.[95,96]

From laboratory to cushion: appropriate models for research and application

This comparative review raises a number of interdisciplinary questions about how best to investigate, model, and apply contemplative practices today. Careful consideration of those questions led me to four main conclusions, one that confirmed the outcome of a prior investigation and three that addressed the main premises that this paper was meant to examine. These conclusions support the assumption that the subtle body is a model of the human nervous system and challenge the priority and exclusivity of current CNS models. They also suggest that this ancient model anticipated modern views of mind and nervous system in key ways.

Second, the conclusions challenge current consensus models of meditation and its neural mechanisms. They suggest the possibility of a typology of contemplative practices based not on their phenomenological or procedural features, but on their underlying neural substrates and mechanisms. The subtle body model challenges modern researchers to explore typologies that more discretely and accurately map the practices that they study onto their neural substrates and mechanisms. I have proposed two such typologies based on the subtle body, elsewhere,[4,6–8] which can be related to current consensus models,[15,17,18] but are more neurally based and comprehensive.

Third, the characteristics of the subtle body—as an embodied network model of CNS function—challenge modern researchers to stretch their brain-centric models to more graphically represent the functional connectivity of the brain with the heart, gut, genitourinary, endocrine, and immune systems. It challenges meditation researchers in particular to develop functional network models that can clearly depict the specific effects and mechanisms of the practices that they study, while also representing the general effects and mechanisms of the vertical and lateral integration promoted by self-regulatory practices as a whole.

Fourth, methodologically, this study challenges meditation researchers to entertain embodied network models of mind–brain–body integration, such

as the subtle body, as interoceptive teaching and neurofeedback aids to support contemplative practice in the ever-expanding range of its practical applications, from stress reduction, self-healing, and preventive health, to enriched learning, creativity, and peak performance.

Supporting Information

Additional supporting information may be found in the online version of this article.

Figure S1. The command hub and spokes mapped onto the prefrontal cortex.

Figure S2. The great bliss hub and spokes mapped onto the sensorimotor cortex.

Figure S3. The enjoyment hub and spokes mapped onto the limbic system.

Figure S4. The primal truth hub and spokes mapped onto the midbrain.

Figure S5. The emanation hub and spokes mapped onto the pons.

Figure S6. The sacral–genital hubs and spokes mapped onto the medulla.

Conflicts of interest

The author declares no conflicts of interest.

References

1. Shannahoff-Khalsa, D. 2012. "Meditation: the science and the art." In *The Encyclopedia of Human Behavior*. Vol. 2. V.S. Ramachandran, Ed.: 576–584. New York: Academic Press.
2. Loizzo, J., L. Blackhall & L. Rabgyay. 2009. "Tibetan medicine: a complementary science of integrative healthcare." In *Longevity, Regeneration & Optimal Health*. W. Bushell & E. Olivo, Eds.: 218–230. New York: Annals of New York Academy of Sciences.
3. Loizzo, J. 2009. "Kālacakra and the Nālandā scientific tradition." In *As Long as Space Endures: Essays on the Kālacakra Tantra in Honor of H.H. the Dalai Lama*. E. Arnold, Ed.: 333–366. Ithaca: Snow Lion.
4. Loizzo, J. 2014. "Meditation research, past, present, and future: perspectives from the Nalanda contemplative science tradition." In *Advances in Meditation Research*. S. Sequiera, Ed.: 43–54. New York: Annals of the New York Academy of Sciences.
5. Loizzo, J. 2012. *Sustainable Happiness: The Mind Science of Well-Being, Altruism, and Inspiration*. New York: Routledge Press.
6. Loizzo, J. 2000. "Meditation and psychotherapy: stress, allostasis and enriched learning." In *Complementary and Alternative Medicine and Psychiatry*. P. Muskin, Ed.: 147–197. Washington, DC: American Psychiatric Association Press.
7. Loizzo, J., M. Charlson & J. Peterson. 2009. "Program in contemplative self-healing: stress, allostasis and enriched learning in the Indo-Tibetan tradition." In *Longevity, Regeneration and Optimal Health: Integrating Eastern and Western Perspectives*. W. Bushell, E. Olivo & N. Thiese, Eds.: 123–147. New York: Annals of the New York Academy of Sciences.
8. Loizzo, J. 2009. "Optimizing learning and quality of life throughout the lifespan." In *Longevity, Regeneration and Optimal Health: Integrating Eastern and Western Perspectives*. W. Bushell, E. Olivo & N. Thiese, Eds.: 186–198. New York: Annals of the New York Academy of Sciences.
9. Leergaard, T.B., C.C. Hilgetag & O. Sporns. 2012. Mapping the connectome: multi-level analysis of brain connectivity. *Front. Neuroinform.* **6:** 14.
10. Perkel, J.M. 2013. This is your brain: mapping the connectome. *Science* **339:** 350–352.
11. White, D.G. 1996. *The Alchemical Body: Siddha Traditions in Medieval India*. Chicago: University of Chicago Press.
12. Loizzo, J. 2006. Recovering the Nalanda legacy: a second renaissance of the Buddhist sciences. In *Proceedings of the International Conference on the Heritage of Nālandā*. R Panth, Ed.: 235–245. New Delhi: Motilal.
13. Loizzo, J. 2006. Renewing the Nālandā tradition: science, religion, and objectivity in Buddhism and the West. *Relig. East West* **6:** 101–120.
14. Thurman, R. 2010. *Brilliant Illumination of the Lamp of the Five Stages*. New York: American Institute of Buddhist Studies.
15. Davidson, R. & A. Lutz. 2008. Buddha's brain: neuroplasticity and meditation. *IEEE Signal Process. Mag.* **25:** 176–174.
16. Vago, D. 2014. "Mapping modalities of self-awareness in mindfulness practice: a potential mechanism for clarifying habits of mind." In *Advances in Meditation Research: Neuroscience and Clinical Applications*. S. Sequiera, Ed.: 28–42. New York: Annals of the New York Academy of Sciences.
17. Vago, D. & D. Silbersweig. 2012. Self-awareness, self-regulation, and self-transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness. *Front. Hum. Neurosci.* **6:** 296.
18. Travis, F. & J. Shear. 2010. Focused attention, open monitoring and automatic self-transcending: categories to organize meditations from Vedic, Buddhist and Chinese traditions. *Conscious. Cogn.* **19:** 1110–1118.
19. Brewer, J.A. & K.A. Garrison. 2014. The posterior cingulate cortex as a plausible mechanistic target of meditation: findings from neuroimaging. *Ann. N.Y. Acad. Sci.* **1307:** 19–27.
20. Brewer, J.A., P.D. Worhunsky, J.R. Gray, *et al.* 2011. Meditation experience is associated with differences in default mode network activity and connectivity. *Proc. Natl. Acad. Sci. U.S.A.* **108:** 20254–20259.
21. Siegel, D. 2007. *The Mindful Brain: Reflection and Attunement in the Cultivation of Wellbeing*. New York: W.W. Norton & Company.
22. Wallace, V. 2001. *The Inner Kālacakratanta*. Oxford: Oxford University Press.
23. Lati, R. & J. Hopkins. 1985. *Death, Intermediate State and Rebirth in Tibetan Buddhism*. Ithaca: Snow Lion.
24. Cozort, D. 1986. *Highest Yoga Tantra*. Ithaca: Snow Lion Press.

25. Clifford, T. 2006. *Tibetan Buddhist Medicine and Psychiatry*. New Delhi: Motilal Banarsidass.
26. Dhonden, Y. 2000. *Healing From the Source: The Science and Lore of Tibetan Medicine*. Ithaca: Snow Lion.
27. Dalai Lama, H.H. & F. Varela. 2002. *Sleeping, Dreaming and Dying: An Exploration of Consciousness*. Somerville: Wisdom Publications.
28. Wedemeyer, C. 2007. *Aryadeva's Lamp that Integrates the Practices*. New York: American Institute of Buddhist Studies.
29. Pandita, L. 2002. *Yamantaka Cycle Texts: Jewel Treasure House of the Three Bodies, Staircase that Leads to the Three Bodies*. Vol. II. New Delhi: Tibet House.
30. Gyaltsen, T.S. 1995. *Yamantaka Cycle Texts: The Profound Path of the Great Secret, Cloud Offerings to Please Manjushri*. Vol. I. New Delhi: Tibet House.
31. MacLean, P. 1990. *The Triune Brain in Evolution*. New York: Plenum Press.
32. Porges, S. 2011. *The Polyvagal Theory: Neurophysiological Foundations of Emotions, Attachment, Communication and Self-Regulation*. New York: W.W. Norton & Co.
33. Shannahoff-Khalsa, D. 1991. Lateralized rhythms of the central and autonomic nervous systems. *Int. J. Psychophysiol.* **11:** 225–251.
34. Shannahoff-Khalsa, D. 2007. Selective unilateral autonomic activation: implications for psychiatry. *CNS Spectr.* **12:** 625–634.
35. Shannahoff-Khalsa, D. 2008. Psychophysiological states: the ultradian dynamics of mind–body interactions. *Int. Rev. Neurobiol.* **80:** 1–220.
36. Cole, M.W., J.R. Reynolds, J.D. Power, *et al.* 2013. Multi-task connectivity reveals flexible hubs for adaptive task control. *Nat. Neurosci.* **16:** 1348–1355.
37. Cozolino, L. 2006. *The Neuroscience of Human Relationships: Attachment and the Developing Brain*. New York: Norton Press.
38. Decety, J. & W. Ickes. 2009. *The Social Neuroscience of Empathy*. Cambridge: MIT Press.
39. Greicius, M.D., B. Krasnow, A.L. Reiss, *et al.* 2003. Functional connectivity in the resting brain: a network analysis of the default mode hypothesis. *Proc. Natl. Acad. Sci. U.S.A.* **100:** 253–258.
40. Raichle, M.E., A.M. MacLeod, A.Z. Snyder, *et al.* 2001. Inaugural article: a default mode of brain function. *Proc. Natl. Acad. Sci. U.S.A.* **98:** 676–682.
41. Critchley, H.D., S. Wiens, P. Rotshtein, *et al.* 2004. Neural systems supporting interoceptive awareness. *Nat. Neurosci.* **7:** 189–195.
42. Stevens, F.L., R.A. Hurley & K.H. Taber. 2011. Anterior cingulate cortex: unique role in cognition and emotion. *J. Neuropsychiatry Clin. Neurosci.* **23:** 121–125.
43. Brewer, J.A., K.A. Garrison & S. Whitfield-Gabrieli. 2013. What about the "self" is processed in the posterior cingulate cortex? *Front. Hum. Neurosci.* **7:** 647.
44. Ho, S.S., R.D. Gonzalez, J.L. Abelson, *et al.* 2012. Neurocircuits underlying cognition–emotion interaction in a social decision making context. *Neuroimage* **63:** 843–857.
45. Reiss, J.P., D.W. Campbell, W.D. Leslie, *et al.* 2005. The role of the striatum in implicit learning: a functional magnetic resonance imaging study. *Neuroreport* **16:** 1291–1295.
46. Grippo, A.J. & A.K. Johnson. 2009. Stress, depression, and cardiovascular dysregulation: a review of neurobiological mechanisms and the integration of research from preclinical disease models. *Stress* **12:** 1–21.
47. Saper, C.B., T.E. Scammell & J. Lu. 2005. Hypothalamic regulation of sleep and circadian rhythms. *Nature* **437:** 1257–1263.
48. Haber, S. 2011. "Neuroanatomy of reward: a view from the ventral striatum." In *Neurobiology of Sensation and Reward*. JA Gottfried, Ed.: 1-45. Boca Raton: Taylor & Francis.
49. Müller-Ribeiro, F.C.F., R.A.L. Dampney, S. McMullan, *et al.* 2014. Disinhibition of the midbrain colliculi unmasks coordinated autonomic, respiratory, and somatomotor responses to auditory and visual stimuli. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* **307:** R1025–R1035.
50. Dick, T.E., D.M. Baekey, J.F. Paton, *et al.* 2009. Cardiorespiratory coupling depends on the pons. *Respir. Physiol. Neurobiol.* **168:** 76–85.
51. Datta, S. 2002. Evidence that REM sleep is controlled by the activation of brain stem pedunculopontine tegmental kainate receptor. *J. Neurophysiol.* **87:** 1790–1798.
52. Dick, T.E., M.A. Haxhiu & N.S. Cherniack. 1992. Salivary secretion elicited by activation of the parabrachial nuclei in the cat. *J. Auton. Nerv. Syst.* **39:** 19–27.
53. Zanzinger, J. 1999. Role of nitric oxide in the neural control of cardiovascular function. *Cardiovasc. Res.* **43:** 639–649.
54. Buckner, R.L. 2013. The cerebellum and cognitive function: 25 years of insight from anatomy and neuroimaging. *Neuron* **80:** 807–815.
55. Gottesmann, C. 1999. The neurophysiology of sleep and waking: intracerebral connections, functioning and ascending influences of the medulla oblongata. *Prog. Neurobiol.* **59:** 1–54.
56. Komisaruk, B.R., B. Whipple, A. Crawford, *et al.* 2004. Brain activation during vaginocervical self-stimulation and orgasm in women with complete spinal cord injury: fMRI evidence of mediation by the vagus nerves. *Brain Res.* **1024:** 77–88.
57. Porges, S.W. 2007. The polyvagal perspective. *Biol. Psychol.* **74:** 116–143.
58. Herman, M.A., M.T. Cruz, N. Sahibzada, *et al.* 2009. GABA signaling in the nucleus tractus solitarius sets the level of activity in dorsal motor nucleus of the vagus cholinergic neurons in the vagovagal circuit. *Am. J. Physiol. Gastrointest. Liver Physiol.* **296:** G101–G111.
59. Purves, D. 2001. "Autonomic regulation of sexual function." In *Neuroscience*. D. Purves, G.J. Augustine, D. Fitzpatrick, *et al.*, Eds. Sunderland: Sinauer Associates.
60. Beary, J. & H. Benson. 1974. A simple psychophysiologic technique which elicits the hypometabolic changes of the relaxation response. *Psychosom. Med.* **36:** 115–120.
61. Kabat-Zinn, J. 1982. An outpatient program based in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. *Gen. Hosp. Psychiatry* **4:** 33–47.

62. Davidson, R. & D. Goleman. 1977. The role of attention in meditation and hypnosis: a psychobiological perspective on transformations of consciousness. *Int. J. Clin. Exp. Hypn.* **25:** 291–308.
63. Josipovic, Z. 2014. "Neural correlates of nondual awareness in meditation." In *Advances in Meditation Research.* S. Sequiera, Ed.: 9–18. New York: Annals of the New York Academy of Sciences.
64. Deikman, A.J. 1971. Bimodal consciousness. *Arch. Gen. Psychiatry* **25:** 481–489.
65. Tang, Y., Y. Ma, Y. Fan, *et al.* 2009. Central and autonomic nervous system interaction is altered by short-term meditation. *Proc. Natl. Acad. Sci. U.S.A.* **106:** 8865–8870.
66. Kabat-Zinn, J., L. Lipworth & R. Burney. 1985. The clinical use of mindfulness meditation for the self-regulation of chronic pain. *J. Behav. Med.* **8:** 163–190.
67. Lutz, A., L. Grieschar, N. Rawlings, *et al.* 2004. Long-term meditators self-induce high amplitude gamma synchrony during mental practice. *Proc. Natl. Acad. Sci. U.S.A.* **101:** 16369–16373.
68. Lazar, S.W., C.E. Kerr, R.H. Wasserman, *et al.* 2005. Meditation experience is associated with increased cortical thickness. *Neuroreport* **16:** 1893–1897.
69. Holtzel, B., J. Carmody, M. Vangel, *et al.* 2011. Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Res.* **191:** 36–43.
70. Tang, Y., Q. Lu, X. Geng, *et al.* 2010. Short-term meditation induces white matter changes in the anterior cingulate. *Proc. Natl. Acad. Sci. U.S.A.* **107:** 15649–15652.
71. Davidson, R., J. Kabat-Zinn, J. Schumacher, *et al.* 2003. Alterations in brain and immune functions produced by mindfulness meditation. *Psychosom. Med.* **65:** 564–570.
72. Hölzel, B.K., U. Ott, T. Gard, *et al.* 2008. Investigation of mindfulness meditation practitioners with voxel-based morphometry. *Soc. Cogn. Affect. Neurosci.* **3:** 55–61.
73. Farb, N.A.S., A.K. Anderson & Z.V. Segal. 2012. The mindful brain and emotion regulation in mood disorders. *Can. J. Psychiatry* **57:** 70–77.
74. Zeidan, F., M. Nichole, M. Emerson, *et al.* 2015. Mindfulness meditation-based pain relief employs different neural mechanisms than placebo and sham mindfulness meditation-induced analgesia. *J. Neurosci.* **35:** 15307–15325.
75. Desbordes, G., L. Negi, T. Pace, *et al.* 2012. Effects of mindful attention and compassion meditation training on amygdala response to emotional stimuli in an ordinary, non-meditative state. *Front. Hum. Neurosci.* **6:** 292.
76. Klimecki, O.M., S. Leiberg, C. Lamm, *et al.* 2013. Functional neural plasticity and associated changes in positive affect after compassion training. *Cereb. Cortex* **23:** 1552–15561.
77. Weng, H.Y., A.S. Fox, A.J. Shackman, *et al.* 2013. Compassion training alters altruism and neural responses to suffering. *Psychol. Sci.* **24:** 1171–1180.
78. Lazar, S.W., G. Bush, R.L. Gollub, *et al.* 2000. Functional brain mapping of the relaxation response and meditation. *Neuroreport* **11:** 1581–1585.
79. Vestergaard-Poulsen, P., M. van Beek, J. Skewes, *et al.* 2009. Long-term meditation is associated with increased gray matter density in the brain stem. *Neuroreport* **20:** 170–174.
80. Davidson, R. 2000. Affective style, psychopathology, and resilience: brain mechanisms and plasticity. *Am. Psychol.* **11:** 1196–1214.
81. Luders, E., O. Phillips, K. Clark, *et al.* 2012. Bridging the hemispheres in meditation: thicker collosal regions and enhanced fractional anisotropy (FA) in long-term practitioners. *Neuroimage* **61:** 181–187.
82. Jella, S. & D. Shannahoff-Khalsa. 1993. The effects of forced nostril breathing on cognitive performance. *Int. J. Neurosci.* **73:** 61–68.
83. Van den Hurk, P., B. Janssen, F. Giommi, *et al.* 2010. Mindfulness meditation associated with alterations in bottom-up processing: psychophysiological evidence for reduced reactivity. *Int. J. Psychophysiol.* **78:** 151–157.
84. Gard, T., M. Taquet, R. Dixit, *et al.* 2014. Fluid intelligence and brain functional organization in aging yoga and meditation practitioners. *Front. Aging Neurosci.* **6:** 76.
85. Lutz, A., J. Brefcyznyski-Lewis, T. Johnstone, *et al.* 2008. Voluntary regulation of the neural circuitry of emotion by compassion meditation: effects of expertise. *PLoS One* **3:** e1897.
86. Kozhevnikov, M., O. Louchakova, Z. Josipovic, *et al.* 2009. The enhancement of visuospatial processing efficiency through Buddhist deity meditation. *Psychol. Sci.* **20:** 645–653.
87. Harinath, K., A.S. Malhotra, K. Pal, *et al.* 2004. Effects of Hatha yoga and Omkar meditation on cardiorespiratory performance, psychologic profile, and melatonin secretion. *J. Altern. Complement. Med.* **10:** 261–268.
88. Amihai, I. & M. Kozhevnikov. 2014. Arousal vs. relaxation: a comparison of the neurophysiological and cognitive correlates of Vajrayana and Theravada meditative practices. *PLoS One* **9:** e102990.
89. Kozhevnikov, M., J. Elliott, J. Shephard, *et al.* 2013. Neurocognitive and somatic components of temperature increases during g-tummo meditation: legend and reality. *PLoS One* **8:** e58244.
90. Benson, H., M. Malhotra, R. Goldman, *et al.* 1990. Three case reports of the metabolic and electroencephalographic changes during advanced Buddhist meditative techniques. *Behav. Med.* **16:** 90–95.
91. Josipovic, Z. 2011. Influence of meditation on anti-correlated networks in the brain. *Front. Hum. Nuerosci.* **5:** 183.
92. Varela, F., E. Thompson & E. Rosch. 1996. *The Embodied Mind: Cognitive Science and Human Experience.* Cambridge: MIT Press.
93. Brough, J. 1951. Theories of general linguistics in the Sanskrit grammarians. *Trans. Philol. Soc.* **50:** 27–46.
94. Kiparsky, P. 1991. "Economy and the construction of the Sivasutras." In *Pāṇinian Studies.* S. Bhate, Ed. Ann Arbor: University of Michigan.
95. Needham, J. 1954–2008. *Science and Civilization in Ancient China.* 7 Vols. Cambridge: Cambridge University Press.
96. Sarton, G. 1927–1948. *Introduction to the History of Science.* 3 Vols. Baltimore: Williams and Wilkins.