

From Sutra to Science: Reinterpreting Yogic Traditions through a Modern Lens

A PRISMA-informed critical synthesis of historical, biomedical and sociocultural evidence up to 2024
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Abstract

Background: Yoga has travelled from aphoristic Sanskrit scholasticism and tantric body-technologies to a globally consumed health practice, accompanied by a rapid expansion of scientific studies. The translation of yogic constructs into biomedical variables is often presented as seamless validation, yet its epistemic costs are seldom audited.

Objective: To reinterpret the core constructs of yogic traditions (mental restraint, posture, breath regulation, meditation and subtle-body anatomy) through the scientific evidence available up to 2024, and to expose where that evidence is strong, weak or conceptually mismatched.

Methods: A critical narrative synthesis, structured with PRISMA 2020 and PRISMA-ScR reporting principles, drew on 100 scholarly sources organised into six evidence domains. Headline quantitative results were extracted from published reviews and trials, cross-checked against their abstracts and compared without pooling across incompatible metrics.

Results: Randomised evidence supports modest, mostly short-term benefits for depressive symptoms (standardised mean difference -0.69 against usual care across 12 trials), cardiometabolic risk markers (systolic blood pressure -5.21 mmHg) and chronic low back pain (small effects, low-to-moderate certainty). Yoga typically outperforms inactive comparators but matches active ones such as exercise. Mechanistic narratives involving GABA, vagal tone, inflammation and telomeres rest largely on small, cross-sectional, uncontrolled or multicomponent studies. Subtle-body constructs have no validated anatomical correlate, and adverse events, though comparable to those of other exercise, are concentrated in specific practices and vulnerable groups. Population use in the United States rose from 9.5% to 14.3% between 2012 and 2017.

Conclusions: Science can legitimately reinterpret yoga as a family of attentional, respiratory and postural skills with measurable, modest health effects, but it cannot validate the soteriological claims of the sutras or the anatomical claims of the subtle body. A credible research agenda requires specified interventions, active and sham comparators, long-term follow-up, safety reporting and an explicit recognition of yoga as an ethically framed, culturally transmitted practice.

Keywords: yoga; Yoga Sutras; Patañjali; prāṇāyāma; meditation; evidence-based medicine; PRISMA; history of yoga; mind-body medicine

1. Introduction

Few cultural exports from South Asia have travelled as widely, or been reinterpreted as thoroughly, as yoga. In 2014 the United Nations General Assembly proclaimed 21 June as the International Day of

Yoga, endorsing the practice as a holistic route to health and well-being [1]. Survey data from the United States illustrate the scale of diffusion: the share of adults reporting yoga use in the preceding twelve months climbed from 9.5% in 2012 to 14.3% in 2017, and women were more than twice as likely as men to practise [2]. Behind these figures lies a quieter but consequential transformation. A discipline whose foundational texts describe the cessation of mental turbulence in the service of liberation has been recast, in clinics, universities and workplaces, as an intervention for blood pressure, back pain and burnout.

The word *sūtra* means a thread, and the aphoristic compression of the classical Yoga Sutras makes the text unusually elastic: it can be read as metaphysics, as psychology, as ethics or, more recently, as an anticipation of neuroscience [3,4]. Contemporary writing frequently advances two claims at once, namely that ancient yogis already knew what science is only now discovering, and that science now confirms what yogis always knew. Both claims deserve scrutiny. The first presumes a continuity of meaning across two millennia and several cultural worlds that historians of yoga have repeatedly questioned [4-6]. The second presumes that laboratory outcomes, such as a shift in a cytokine, a brain scan or a questionnaire score, exhaust the meaning of constructs that were framed as soteriological rather than therapeutic [7,8].

The empirical literature has grown fast enough to make both claims easy to sustain superficially. A bibliometric analysis spanning 1967 to 2013 documented steep growth in published research on yoga as a therapeutic intervention [9], and overview articles generally conclude that yoga benefits a range of mental and physical outcomes [10-13]. Narrative enthusiasm and methodological quality are, however, different things. Many trials are small, unblinded and brief; comparators vary; styles of yoga are rarely standardised; and mechanistic claims frequently outrun the designs that support them [14-16]. A critical reading must therefore hold three registers together: what the traditions actually said, what the best available evidence shows, and what is lost or distorted when the first is translated into the second.

This paper undertakes that task. It is framed as a critical, PRISMA-informed synthesis [17,18] rather than a new meta-analysis, and it is organised around four research questions. RQ1: how have the central constructs of yogic traditions been historically constituted, and how stable is their meaning across textual layers? RQ2: what do systematic reviews and key primary studies published up to 2024 show about the effects and mechanisms associated with these practices? RQ3: where does scientific translation succeed, where is it weak and where is it conceptually mismatched? RQ4: how do historians, clinicians, neuroscientists, sociologists and practitioners differ in defining authentic yoga research, and what do these differences imply for future studies?

The contribution is threefold. First, the paper consolidates verified quantitative results from major reviews into a comparative table and figure, so that effect sizes, certainty ratings and caveats can be read side by side. Second, it audits mechanistic narratives (GABA, vagal tone, inflammation, telomeres) against the study designs that actually underpin them. Third, it places Indian socio-cultural scholarship on language, ritual formation and ethics [19-23] alongside biomedical evidence, arguing that a credible research agenda must treat yoga as a lived, transmitted and ethically framed practice, not merely as an exercise modality.

Section 2 reconstructs the historical and conceptual background and Section 3 describes the methods. Section 4 reviews related research and its outputs, Section 5 reinterprets core constructs mechanistically, Section 6 offers comparative analysis, Section 7 exposes the principal methodological and conceptual weaknesses, and Section 8 compares disciplinary perspectives. Sections 9 to 11 set out implications, limitations and conclusions.

2. Conceptual and Historical Background

2.1 The sutra layer

The Yoga Sutras attributed to Patañjali are a compact collection of roughly two hundred aphorisms arranged in four chapters. The second aphorism defines yoga as the stilling of the fluctuations of the mind, and the text proposes a graded path, commonly summarised as eight limbs, running from ethical restraints and observances through posture, breath regulation, sensory withdrawal, concentration, meditation and absorption [3]. The metaphysical frame is a dualism adapted from Sāṃkhya, in which an inactive witnessing consciousness (*puruṣa*) is distinguished from the creative, ever-transforming matrix of nature (*prakṛti*), and suffering arises from mistaking one for the other [3,24]. Liberation in this scheme is a cognitive-existential event of discrimination, not a physiological state.

Two features of this layer matter for scientific translation. First, posture occupies a strikingly small place: the text addresses it in only a few aphorisms and characterises it by steadiness and ease rather than by an inventory of shapes [3]. Second, the philological record is contested. Recent scholarship places the composite of root text and commentary in roughly the early fifth century CE, although the dating of the aphorisms themselves remains debated [4,25]. White further argues that the text enjoyed a modest premodern career and was raised to canonical status largely through nineteenth- and twentieth-century reinterpretation [4]. A researcher who cites "Patañjali" as a clinical authority is therefore leaning on a historically constructed authority.

2.2 The tantric and haṭha layer

A different current runs through the texts of the second millennium CE grouped under the label *haṭha yoga*. Rooted in tantric and ascetic milieus, these works present yoga as a set of bodily technologies, namely postures, locks, seals and breath retentions, intended to channel vital energy, preserve bodily essences and awaken a latent power conventionally named *kuṇḍalinī* [26-28]. The semantic range of the word *haṭha*, often rendered simply as "force", has been traced to technical senses that differ from later popular interpretations [27]. The postural repertoire of these premodern manuals was also modest: a widely cited fifteenth-century text describes on the order of fifteen postures, several of them seated positions for meditation and breath control rather than the dynamic sequences familiar today [29]. The subtle-body model of channels and energy centres (*nāḍī*, *cakra*) developed over centuries with considerable variation in number and arrangement [28], and the now-familiar seven-centre scheme was popularised in English largely through early twentieth-century translation [30].

2.3 The modern layer

Modern yoga is a third layer, and probably the one most relevant to contemporary research participants. Singleton's historical analysis argues that twentieth-century postural yoga emerged from a dialogue between Indian reformers and global physical-culture movements, including gymnastics and

callisthenics, rather than from an unbroken ancient lineage of posture practice [5]. De Michelis distinguishes modern postural, meditational, devotional and denominational forms and shows how Vivekananda's reinterpretation of the Yoga Sutras shaped Western understanding [6]. Alter's study of early scientific yoga in India shows that the project of validating yoga in physiological laboratories began in the 1920s, so that "from sutra to science" is itself a century-old enterprise with its own nationalist and reformist motives [31]. Systematisation by influential teachers then standardised postures into a codified catalogue of some two hundred forms [32], and later commodification and global branding added a further interpretive layer [33-35]. Edited scholarship on cross-cultural translation underlines that "yoga" is plural, historically contingent and continually remade [36].

2.4 Transmission and cultural embedding

Yoga has always been transmitted through relationships and languages, not through manuals alone. Sociological work on language, *saṃskāra* (formative impressions and rites) and culture in the Indian context emphasises that cultural continuity depends on repeated, socially embedded practices through which values and dispositions are inherited [19-21]. Read alongside the yogic notion of latent impressions that condition the mind, this literature suggests why decontextualised interventions may behave differently from embedded practice: the Sanskrit vocabulary, the teacher–student bond and the ethical vows are part of the technology, not ornament. The ethical limbs of yoga, notably non-violence and truthfulness, also resonate with twentieth-century Indian moral thought. Analyses of Gandhian values and of Gandhi's educational thinking stress morality and life skills as the core of personal formation [22,23], offering a bridge between classical ethics and modern civic education. These strands matter for research design because they imply outcomes (ethical conduct, social engagement, meaning) that clinical trials rarely measure.

3. Methodology

3.1 Design and reporting framework

This study is a critical narrative synthesis conducted with the transparency principles of PRISMA 2020 [17] and, because its aim is to map and appraise a heterogeneous conceptual and empirical landscape, the structure of the PRISMA extension for scoping reviews [18]. A conventional systematic review demands a narrowly framed question, such as the effect of one intervention on one outcome. The present question differs: it asks how a family of historically layered constructs has been operationalised across disciplines. The unit of synthesis is therefore the construct, not the intervention, and no new quantitative pooling was attempted. Scoping approaches are designed for clarifying concepts and identifying knowledge gaps [18], which is the purpose served here.

3.2 Eligibility criteria

Eligible sources were scholarly books, peer-reviewed articles and official statistical reports that (i) addressed the textual, historical or philosophical foundations of yoga; (ii) reported or synthesised clinical, physiological, neuroimaging or biomarker outcomes of yoga or closely related contemplative practice; (iii) examined safety or adverse events; (iv) described patterns of use; (v) concerned research methodology, reproducibility or critique; or (vi) provided Indian socio-cultural, ethical or institutional context. Because the paper is intended for the 2025 publication cycle, only sources published on or before 31 December 2024 were eligible; later records were excluded irrespective of relevance. Sources

were English-language, with the exception of Hindi-language sociological studies from the author-maintained collection described below, for which English renderings of titles are supplied.

3.3 Selection process and evidence base

Two streams contributed to the evidence base. The first was an author-maintained reference collection of 117 records. Each record was screened first for date and then for thematic relevance. Eighteen records were dated 2024 or earlier; sixteen of these were retained and two were excluded for lacking thematic relevance to yoga, culture, ethics or institutional context. The remaining 99 records, dated 2025 or later or undated, were excluded under the date rule. The second stream consisted of externally published literature selected purposively to cover the six evidence domains, prioritising Cochrane and other systematic reviews, widely cited randomised and mechanistic studies, authoritative historical monographs and meta-research. In total, 84 external sources were retained, so that 100 sources informed the synthesis. The selection flow is shown in Figure 1.

Because the second stream was purposive rather than an exhaustive database search, the review does not report database-specific record counts. It should be read as an evidence-informed critical synthesis, not a complete systematic census, a limitation discussed in Section 10.

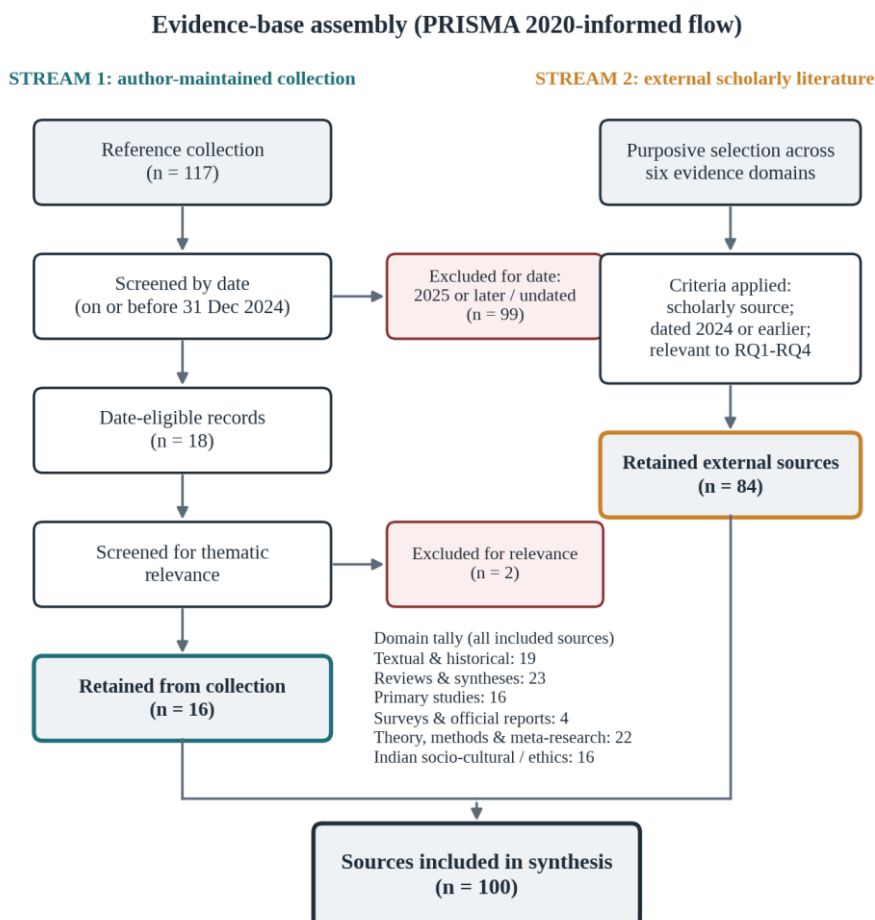


Figure 1. Selection flow for the evidence base, adapted from the PRISMA 2020 flow convention. The second stream was purposive; database-specific record counts are therefore not reported.

3.4 Data items and verification

For each quantitative source, design, sample size, comparator, effect metric and the authors' own certainty or risk-of-bias judgement were extracted. Headline figures reported in Table 1 and Figure 2 were cross-checked against the published abstracts to prevent transcription error. Effect metrics were not pooled across sources, because standardised mean differences, raw mean differences and proportions answer different questions and derive from different comparators.

3.5 Quality appraisal

Methodological quality was judged narratively with reference to the Cochrane risk-of-bias framework for randomised trials [37], the AMSTAR 2 domains for systematic reviews [38] and the certainty-of-evidence conventions described in the Cochrane Handbook [39]. Where an original review had already graded certainty, the authors' grading was reported rather than re-derived. Historical and philological sources were appraised for disciplinary standing, evidentiary basis and whether their claims were contested in the secondary literature.

3.6 Ethical considerations and originality

The study used only published secondary data and involved no human participants, so formal ethical approval was not required. The work followed accepted ethical principles for social-science research, including accurate attribution and transparent reporting of limitations [40]. The text was composed afresh for this synthesis, with all sources paraphrased and attributed; independent similarity screening with recognised plagiarism-detection tools remains advisable before submission [41].

4. Related Research Reviews and Their Outputs

This section synthesises the principal reviews and landmark primary studies that define the current evidence base. Their design, sample, headline results and caveats are collated in Table 1, and the reading that follows concentrates on what the pattern of results means for the translation of yogic practice into health claims.

4.1 Overview-level reviews

Several overview articles have summarised the health effects of yoga. A short summary of reviews concluded that yoga showed favourable effects across mental and physical outcomes while stressing the need for better trials [10]. A review of studies that matched yoga against conventional exercise found that yoga performed at least as well as exercise on many outcome measures [11], a more modest and more informative claim than superiority. Narrative reviews of clinical research and of pranayama-oriented research reached broadly positive conclusions while acknowledging methodological shortfalls [12,13]. The bibliometric portrait of the field showed that the literature expanded rapidly over four decades, but expansion in volume is not expansion in rigour [9].

4.2 Depression, anxiety and trauma

The most developed evidence concerns depression and anxiety. The meta-analysis by Cramer and colleagues pooled twelve randomised trials with 619 participants and reported moderate-certainty short-term benefit relative to usual care (standardised mean difference [SMD] -0.69 , 95% CI -0.99 to -0.39), with limited evidence of benefit relative to relaxation (SMD -0.62) and aerobic exercise (SMD -0.59). Only three of the twelve trials had low risk of bias, no long-term pooling was possible and no trial reported safety data [14]. Subsequent reviews broadened the question. A meta-analysis of trials in people with psychiatric disorders reported lower depressive symptoms with yoga [42]; a review focused on hatha yoga for mood and anxiety disorders reached cautiously positive conclusions [43]; and meta-analyses addressing anxiety likewise found encouraging results while the authors emphasised heterogeneity and limits in study quality [44,45].

In trauma, a randomised trial of 64 women with chronic, treatment-resistant post-traumatic stress disorder found that, after ten weekly sessions, 52% of the yoga group (16 of 31) no longer met diagnostic criteria compared with 21% (6 of 29) of a women's health education control group [46]. The trial's authors themselves acknowledged a demographically narrow sample. Neurobiological rationales, including proposed effects on stress-response systems and inhibitory neurotransmission, have been articulated [47,48], but they remain hypotheses rather than established mechanisms.

4.3 Chronic low back pain

For chronic non-specific low back pain, a meta-analysis of randomised trials reported benefits for pain and disability [49]. The Cochrane review, which included 21 trials with 2,223 participants, rated the evidence as low to moderate in certainty and described the improvements in back-related function and pain relative to no exercise as small and not clinically important at three months, while finding little or no difference relative to other back-focused exercise [15]. No included trial compared yoga with a sham yoga condition, so specific effects cannot be separated from non-specific ones [15]. Primary trials tell the same story. Yoga and conventional stretching both outperformed a self-care book in a 101-participant trial [50], and a 320-participant noninferiority trial found yoga comparable to physical therapy [51]. These findings support yoga as one of several reasonable exercise options, not as a uniquely effective treatment.

4.4 Cardiometabolic outcomes

Screening 1,404 records, Chu and colleagues included 37 randomised trials, 32 of them in meta-analysis. Against non-exercise controls, yoga was associated with lower body mass index (-0.77 kg/m²), lower systolic blood pressure (-5.21 mmHg), lower LDL cholesterol (-12.14 mg/dL) and higher HDL cholesterol ($+3.20$ mg/dL), without significant change in fasting glucose or glycated haemoglobin and without significant difference from conventional exercise. The authors cautioned that trials were small, heterogeneous and of moderate quality [16]. A Cochrane review on primary prevention of cardiovascular disease took a more reserved view of the same body of evidence, citing quality limitations [52]. A blood-pressure reduction of this order would matter at population level if sustained, but sustainability is precisely what few trials test.

4.5 Cognition and attention

A meta-analysis of chronic and acute effects of yoga on cognition reported improvements in domains such as executive function, attention and processing speed, with effect sizes varying by population and design [53]. These results are conceptually closest to the classical aim of regulating attention, but the outcomes are neuropsychological tests, not the discriminative insight the sutras envisage [3].

4.6 Meditation as a benchmark

Reviews of meditation provide a benchmark against which yoga can be compared. A review of 47 trials with 3,515 participants found moderate evidence that mindfulness meditation programmes improve anxiety (effect size 0.38 at eight weeks), depression (0.30) and pain (0.33), with low or insufficient evidence for other outcomes and no evidence of superiority over active treatments such as drugs, exercise or other behavioural therapies [54]. A later review of mindfulness and psychopathology offered a more differentiated, disorder-specific appraisal [55]. The mindfulness field has also produced a self-critical literature on hype, definitional vagueness and measurement [56]. This matters for yoga because many yoga trials embed meditative components and share a mindful-attention rationale [57,58].

4.7 Safety

Safety research has moved from anecdote to synthesis. A systematic review of 35 case reports and two case series identified 76 adverse events, of which 35.5% involved the musculoskeletal system, 18.4% the nervous system and 11.8% the eyes, with headstand, shoulder stand, lotus position and forceful breathing among the most frequently implicated practices [59]. Because case reports cannot yield

incidence, a later review of 94 randomised trials with 8,430 participants examined the question prospectively and concluded that the frequency of adverse events in yoga groups was comparable to that with usual care and other exercise [60]. Reporting of adverse events was nonetheless inconsistent across trials, and the case-report evidence indicates that risk concentrates in particular poses and vulnerable people, notably those with glaucoma or compromised bone density [59]. In the meditation literature, mixed-methods studies have documented challenging experiences among practitioners, and conceptual work has sought to define and measure such effects [61,62].

4.8 Patterns of use

Epidemiological studies describe who practises. In the United States, yoga use rose from 9.5% to 14.3% between 2012 and 2017; in 2017, 19.8% of women and 8.6% of men reported use, and uptake was highest among adults aged 18 to 44 [2]. A systematic review of correlates of yoga practice found it concentrated among women and, in many samples, among more highly educated adults [63]. A UK survey explored practitioners' motives and perceived benefits [64]. Practitioner profiles may therefore differ from the populations that bear the greatest burden of chronic disease, a point that bears on the external validity of the trials.

Table 1. Comparative matrix of principal reviews and landmark studies (data cross-checked against published abstracts; metrics are not pooled).

Source	Design and sample	Headline result	Certainty / principal caveat
[14]	Systematic review and meta-analysis; 12 RCTs, 619 participants; yoga for depression	Short-term SMD -0.69 (95% CI -0.99 to -0.39) vs usual care; -0.62 vs relaxation; -0.59 vs aerobic exercise	Moderate (vs usual care) to limited; only 3 of 12 trials at low risk of bias; no long-term pooling; no safety data
[54]	Systematic review and meta-analysis; 47 RCTs, 3,515 participants; meditation programmes	Mindfulness: anxiety ES 0.38 (0.12 – 0.64) at 8 weeks; depression 0.30 (0.00 – 0.59); pain 0.33 (0.03 – 0.62)	Moderate for these outcomes, low or insufficient for others; no evidence of superiority over active treatments
[16]	Systematic review and meta-analysis; 37 RCTs (32 pooled) from 1,404 records; cardiometabolic risk	Vs non-exercise: BMI -0.77 kg/m ² ; SBP -5.21 mmHg; LDL -12.14 mg/dL; HDL $+3.20$ mg/dL; glucose and HbA1c not significant	Moderate-quality, small, heterogeneous trials; no significant difference from exercise
[15]	Cochrane review; 21 RCTs, 2,223 participants; chronic non-specific low back pain	Vs no exercise at 3 months: small improvements in function and pain, judged not clinically important; little or no difference vs back-focused exercise	Low to moderate certainty; no sham-yoga trials
[46]	RCT; 64 women with chronic, treatment-resistant PTSD; 10 weekly sessions	52% (16/31) of yoga group vs 21% (6/29) of control no longer met PTSD criteria	Single trial; narrow, relatively well-educated US sample; adjunctive use
[65]	RCT; 12 weeks; yoga (n = 19) vs walking (n = 15); MRS of brain GABA	Greater improvement in mood and anxiety with yoga; thalamic GABA changes correlated with symptom change	Small sample; correlation does not demonstrate mediation

Source	Design and sample	Headline result	Certainty / principal caveat
[66]	Experimental cross-sectional comparison; 50 women (25 novices, 25 experts)	IL-6 41% higher in novices; 4.75-fold odds of detectable CRP; no unique inflammatory effect of a single session	Cannot separate training effect from self-selection
[59]	Systematic review; 35 case reports and 2 case series; 76 cases	Adverse events: 35.5% musculoskeletal, 18.4% nervous system, 11.8% eyes	Case reports cannot estimate incidence
[60]	Systematic review and meta-analysis; 94 RCTs, 8,430 participants; safety	Frequency of adverse events comparable to usual care and other exercise	Adverse-event reporting inconsistent across trials
[2]	Nationally representative US survey; 2012 vs 2017	Yoga use 9.5% to 14.3%; in 2017, women 19.8% vs men 8.6%; meditation 4.1% to 14.2%	Self-reported use; United States only

4.9 What the reviews jointly imply

Four regularities emerge from Table 1. First, effect sizes are small to moderate and are typically reported for short follow-up periods. Second, certainty ratings are low to moderate, mainly because of risk of bias, small samples and inconsistency. Third, comparator type determines the narrative: yoga tends to beat inactive controls and to match active ones, which suggests that part of its benefit lies in features shared with other structured activity, such as movement, attention, social contact and expectation. Fourth, the literature is much richer in outcome data than in mechanism data, and the mechanistic claims that circulate most widely rest on the weakest designs. Each of these regularities is revisited in Sections 5 to 7.

5. Reinterpreting Core Constructs Through Mechanistic Science

5.1 Mental restraint (*citta-vṛtti-nirodha*) as attentional regulation

The central aim of the sutras, the stilling of mental fluctuation [3], has no direct physiological referent. What science can measure are proxies: sustained attention, reduced rumination, emotion regulation and metacognitive awareness. Frameworks proposed to explain yoga's psychological effects identify self-regulatory components, namely attention control, emotion regulation, body awareness and changes in self-perception, that parallel those proposed for mindfulness [57,58]. A neurophysiological framework further distinguishes top-down mechanisms, in which practice engages cortical regulation of arousal, from bottom-up mechanisms that operate through interoceptive and autonomic channels [67].

Structural imaging adds to the picture. An eight-week mindfulness-based stress-reduction programme was followed by increased grey-matter density in the hippocampus in sixteen participants [68], and cross-sectional work found greater cortical thickness in experienced meditators [69]. These findings are suggestive but modest in sample size, and the cross-sectional comparison cannot separate training from self-selection. The translation problem is conceptual as well as statistical. In the sutras the end point is discriminative knowledge; in the laboratory the end point is a score. A reduction in rumination is not equivalent to liberation; at best it is a correlated precondition that the tradition would regard as instrumental.

5.2 Breath regulation (*prāṇāyāma*) and autonomic function

In the classical text, breath regulation follows the establishment of posture and concerns the regulation or arrest of the movement of inhalation and exhalation [3]. Modern research, in contrast, typically studies slow, paced or alternate-nostril breathing. A systematic review of slow breathing identified associations with increased heart-rate variability and with changes in brain activity and emotional state, while noting small studies and heterogeneous protocols [70]. Proposed mechanisms invoke effects on pulmonary stretch receptors and autonomic balance [71], and a neurophysiologic model of rhythmic yogic breathing for stress and anxiety has been advanced [72]. Experimental work on nostril-specific techniques reported immediate changes in autonomic and respiratory variables [73], and a comprehensive review of yoga and heart-rate variability found generally favourable but heterogeneous results [74].

A popular interpretive overlay is polyvagal theory, used to explain yoga as a means of strengthening vagal regulation [75,76]. The theory is contested: critics argue that its claims about the evolution and function of vagal pathways, and about respiratory sinus arrhythmia as an index of vagal tone, are not supported by comparative physiology and psychophysiology [77]. Prudence therefore calls for describing breathing effects as changes in measured autonomic variables, not as confirmed activation of a particular neural circuit.

5.3 Posture (*āsana*), neurochemistry and the brain

Magnetic resonance spectroscopy studies of the inhibitory neurotransmitter GABA are frequently cited. A pilot study of experienced practitioners reported a significant rise in thalamic GABA after a single hour of yoga relative to a reading control [78]. A later 12-week randomised study found that a yoga group ($n = 19$) improved more in mood and anxiety than a metabolically matched walking group ($n = 15$), with changes in thalamic GABA correlating with symptom change [65]. These are creative designs, but samples are small, the GABA measure is regional and indirect, and correlation within groups does not demonstrate mediation. Related work shows that long-term practitioners tolerate pain better and differ in insular structure from non-practitioners [79], yet cross-sectional comparison cannot separate the effects of training from the characteristics of people who choose to train.

For physical outcomes the mechanistic story sits closer to exercise physiology, and head-to-head comparisons suggest equivalence on many outcomes [11,15,16]. Because the classical text defines posture by its quality (steady and comfortable) [3] while trials prescribe sequences of shapes, an unresolved question is whether "āsana" in studies bears any resemblance to the textual practice.

5.4 Stress, inflammation and immunity

A pivotal cross-sectional experiment compared 25 novice and 25 expert female practitioners. Interleukin-6 was 41% higher in novices across sessions and their odds of detectable C-reactive protein were 4.75 times those of experts, yet a single yoga session produced no distinctive inflammatory change relative to control conditions [66]. This pattern points to cumulative or trait differences but cannot establish that yoga caused them. Randomised pilot work is more direct: a yogic meditation intervention in dementia caregivers reversed pro-inflammatory gene-expression dynamics [80], and a yoga programme reduced inflammatory signalling in fatigued breast-cancer survivors [81]. Both trials were small. An uncontrolled study of a three-month retreat observed changes in neurotrophic, endocrine and

inflammatory markers [82]. A meta-analysis of stress-related physiological measures found that yoga and mindfulness-based stress reduction were associated with improvement in some markers, with substantial heterogeneity and quality concerns [83].

5.5 Cellular ageing

Telomere biology has become a symbolic marker for "anti-ageing" claims. Conceptual work proposed that chronic stress accelerates cellular ageing and that mindfulness might buffer the process [84]. A pilot study of comprehensive lifestyle change that included yoga-based stress management reported increased telomerase activity, but the multicomponent design (diet, exercise, stress management and social support) prevents attribution to yoga alone [85]. A small study of a yoga-based lifestyle intervention likewise reported changes in telomerase activity [86]. At present, evidence that yoga lengthens telomeres or slows biological ageing is preliminary: studies are small, mostly uncontrolled or multicomponent, and use a surrogate whose clinical meaning is debated.

5.6 The subtle body (*nāḍī, cakra, kuṇḍalinī*)

No technology has demonstrated an anatomical structure corresponding to the *nāḍī* or *cakra*. Historical scholarship shows that the energy centres were models within ritual and meditative systems whose number, location and symbolism varied by lineage [28], and that the contemporary seven-centre template is a relatively recent crystallisation shaped by translation and esoteric interpretation [6,30]. Efforts to map *cakras* onto endocrine glands or nerve plexuses are therefore analogical rather than empirical. A defensible scientific reinterpretation treats them as phenomenological maps of interoceptive experience, that is, culturally structured descriptions of sensations and attentional foci that can be studied through interoception, body awareness and self-report methods [58,67]. The same reasoning applies to *kuṇḍalinī*, which the haṭha literature presents as a latent power awakened by technique [26,28]. Since intense practices have been associated with distressing experiences in some practitioners [59,61], research on these constructs should be cautious and non-sensational.

5.7 Ethical limbs and social formation

The first two limbs, ethical restraints and observances, are almost absent from clinical trials. This omission is not trivial. If yoga is understood as a path of conduct, outcomes such as prosocial behaviour, civic responsibility and moral development are central, not peripheral. Indian discussions of Gandhian values and moral education [22,23] supply ready-made constructs (non-violence, truthfulness, self-discipline) that could be operationalised in mixed-methods designs, and sociological work on *saṃskāra* offers a vocabulary for studying how dispositions are acquired and transmitted [19-21].

6. Comparative Analysis

6.1 Construct-by-construct comparison

Table 2 aligns the principal yogic constructs with their modern operationalisations, representative evidence and evidential status. It shows an uneven terrain. Constructs that map onto observable behaviour or physiology, namely posture, breath and meditation, have measurable and usually modest effects, whereas constructs that are ontological (*puruṣa*), soteriological (liberation) or anatomical (*cakra*) are not testable in the form in which the traditions state them.

Table 2. Yogic constructs, modern operationalisations and evidential status.

Construct	Classical sense	Modern operationalisation	Key sources	Evidential status
<i>Citta-vṛtti-nirodha</i>	Stilling of mental fluctuations as the aim of yoga [3]	Attention control, reduced rumination, emotion regulation	[57,58,68,69]	Plausible proxies, small samples; a score is not equivalent to the classical end point
<i>Āsana</i>	Steady, comfortable posture; few aphorisms [3]	Physical activity, flexibility, musculoskeletal function, cardiometabolic markers	[11,15,16]	Small to moderate effects; broadly equivalent to exercise; low-to-moderate certainty
<i>Prāṇāyāma</i>	Regulation of the movement of breath [3]	Slow or paced breathing; heart-rate variability; autonomic measures	[70,73,74,77]	Promising but heterogeneous; polyvagal interpretation contested
<i>Dhyāna</i> (meditation)	Sustained meditative absorption [3]	Mindfulness-type programmes; anxiety, depression, pain	[54-56]	Small to moderate effects; no superiority over active treatments; adverse experiences documented [61,62]
<i>Yama-niyama</i>	Ethical restraints and observances [3]	Prosocial conduct, moral development, civic engagement	[22,23]	Largely untested in trials; context from Indian moral thought
<i>Cakra / kuṇḍalinī</i>	Subtle-body centres and latent power [26,28]	Interoception and phenomenology; analogies to plexuses or glands	[30,67]	No validated anatomical correlate; analogical, not empirical
<i>Duḥkha / kleśa</i>	Suffering and its afflictions [3]	Stress reactivity, allostatic load, inflammation	[66,80,81,83]	Associational; mostly small or cross-sectional; causal pathways unvalidated

6.2 Yoga against other modalities

Figure 2 juxtaposes two kinds of verified quantitative data: the trajectory of population use, and effect sizes reported in major reviews. Because the effect measures derive from different comparators, outcomes and populations, the figure is a visual aid to magnitude, not a pooled estimate. Across conditions, a consistent pattern appears. In depression, yoga beat usual care and showed limited evidence of benefit over relaxation and aerobic exercise [14]. In cardiometabolic risk, no significant difference from exercise was found [16]. In low back pain, there was little or no difference from other back-focused exercise [15]. In mindfulness meditation, no evidence of superiority over active treatments emerged [54]. Yoga therefore tends to exceed inactive comparators and to equal active ones.

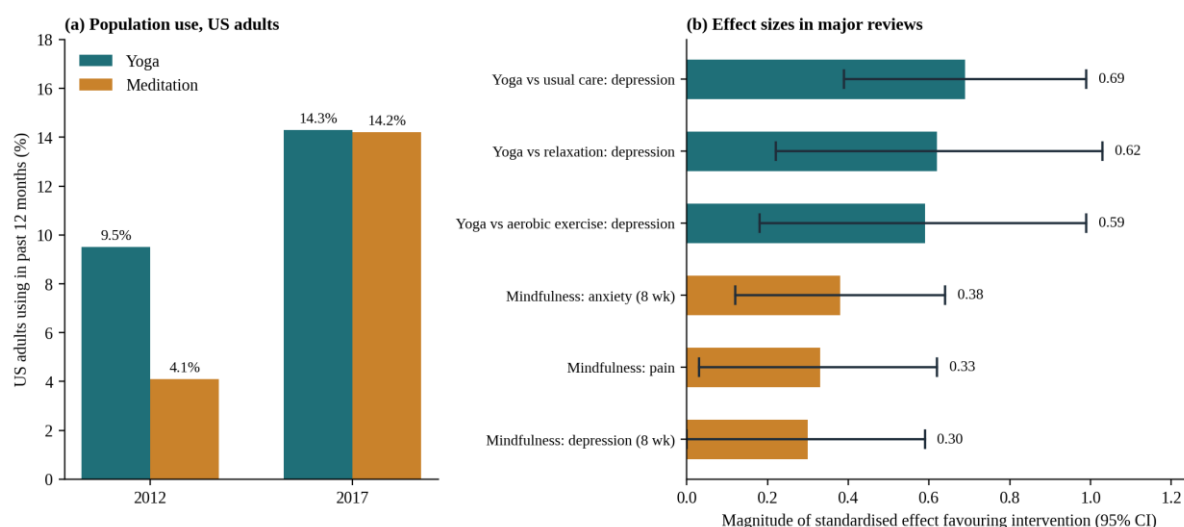


Figure 2. Comparative data: (a) self-reported use of yoga and meditation among US adults, 2012 and 2017 [2]; (b) magnitude of standardised effects with 95% confidence intervals for yoga in depression [14] and for mindfulness meditation programmes [54]. Effect measures derive from different comparators and outcomes and are not pooled.

This pattern is easily misread in either direction. Enthusiasts may read equivalence as vindication; sceptics may read it as irrelevance. The more defensible reading is that yoga is a credible, low-cost member of the family of structured, attention-demanding physical and mental activities, whose particular strengths (accessibility, integration of breath, movement and attention, and cultural appeal) may help adherence even if they do not confer unique physiological advantage [11,16]. The tradition, for its part, never claimed superiority at lowering blood pressure; the demand for comparative superiority is a feature of biomedical framing, not of yogic self-understanding.

6.3 Yoga and Buddhist meditation

Comparison with Buddhist-derived mindfulness is instructive. Both traditions train attention and emotional regulation, and contemporary research frames their psychological effects in overlapping terms [55,57]. Both also face concerns about overstated claims and adverse effects [56,62]. Their metaphysical commitments, however, differ sharply: the Yoga Sutras presuppose a witnessing consciousness distinct from nature [3,24], whereas Buddhist traditions develop their meditative systems within different ontological and soteriological frameworks [7,8]. Secular outcome measures are blind to this difference, which is why two practices that look alike in a trial may have quite different intended meanings. Any comparative neuroscience of the two must specify not only techniques but also the interpretive frameworks within which practitioners understand them [67].

6.4 The trajectory of popular uptake

Utilisation data complete the comparison. Between 2012 and 2017 yoga use among US adults rose from 9.5% to 14.3%, while meditation use more than tripled, from 4.1% to 14.2% [2]. The rate of cultural diffusion has outpaced the evidence base, and public enthusiasm is no substitute for the cumulative, replicated trials needed to establish when yoga should be recommended and to whom.

6.5 A translational framework

The preceding comparisons can be condensed into a layered framework (Figure 3). The first layer comprises the classical constructs: mental restraint, posture, breath regulation, meditation, ethical restraint and subtle-body models, each embedded in a textual setting whose meaning is historically specific [3,29]. The second layer comprises the mechanistic hypotheses that scientists have proposed to connect those constructs to the body: attentional and emotional regulation, autonomic modulation, neuroendocrine and inflammatory pathways, and cellular-ageing processes [58,67]. The third layer comprises measured outcomes, namely symptom scales, blood pressure, lipid levels, functional status and biomarkers [14-16]. The links between layers are not equal in strength. The link from outcomes back to mechanisms is weak in most studies, because outcomes are measured but mechanisms are not tested with adequate designs, and the link from mechanisms back to classical constructs is conceptual rather than empirical, because the hypotheses are modern while the constructs are classical.

Two further features distinguish the framework from a simple pipeline. A band of cultural, ethical and relational context surrounds all three layers, representing the language, transmission and moral formation through which practices acquire meaning [19-21]. And a set of translation filters (specification of the intervention, appropriate comparators, long follow-up and safety reporting) governs how far an outcome can be attributed to a construct [60,87,88]. The framework's practical value is diagnostic: for any claim that circulates about yoga, one can ask which layer it concerns, which link it relies on and which filter it has passed.

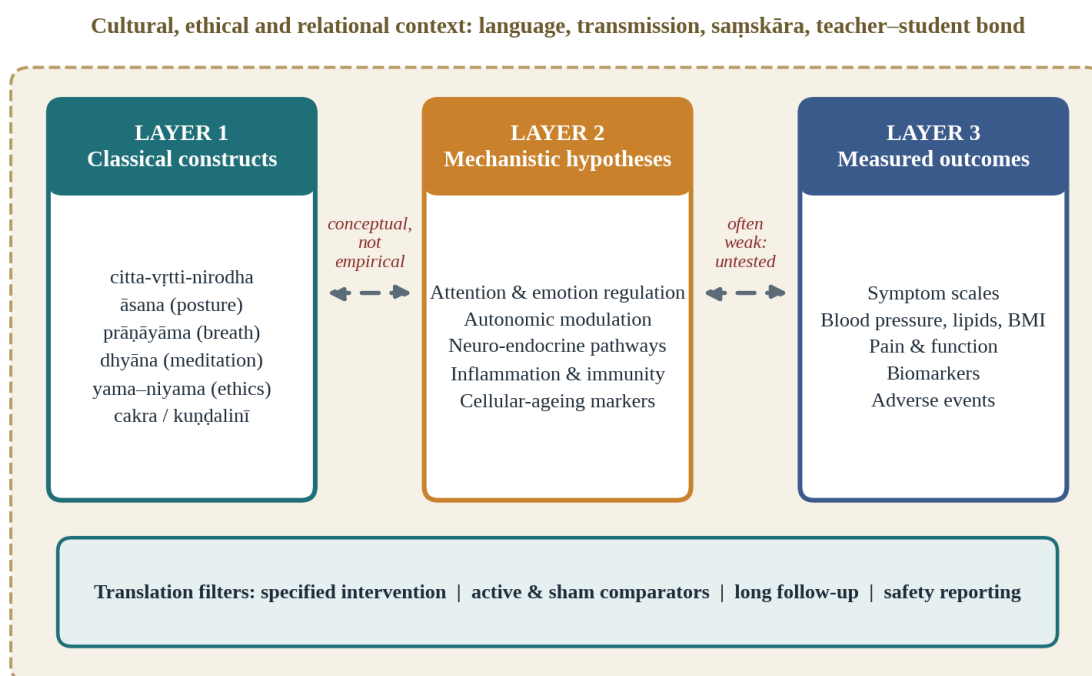


Figure 3. Layered translational framework linking classical constructs, mechanistic hypotheses and measured outcomes within a cultural, ethical and relational context.

7. Analytical Reality Exposing: Where the Translation Fails

A critical synthesis owes the reader an account of where the scientific reinterpretation of yoga is least secure. Eleven fault lines emerge from the evidence above.

7.1 Risk of bias and certainty of evidence

The depression meta-analysis is illustrative: of twelve trials, only three were judged at low risk of bias, and long-term effects could not be pooled [14]. The Cochrane back-pain review graded the evidence as low to moderate in certainty [15], and the cardiometabolic meta-analysis described trials as small, heterogeneous and of moderate quality [16]. When pooled estimates are drawn from weak trials, confidence intervals understate true uncertainty, and the headline effect sizes may overstate the benefit that a typical patient would experience.

7.2 Blinding, expectancy and the absence of a sham

Participants in a yoga class know that they are doing yoga. The Cochrane review explicitly noted the absence of sham-yoga comparators [15], so specific effects cannot be distinguished from expectancy, attention from an instructor, group support or time spent in a calming setting. The equivalence between yoga and other active conditions [11,16,54] is consistent with a large non-specific component. This does not make benefits unreal; it makes their attribution uncertain.

7.3 The heterogeneity of "yoga"

Trials label very different interventions "yoga": gentle restorative sequences, vigorous flows, breath-centred programmes, meditation-heavy retreats and multicomponent lifestyle packages. A scoping review of yoga intervention components and study quality highlighted the variability of what is reported about style, dose and delivery [89], and published guidance exists for developing and describing yoga interventions in randomised trials [88]. Without such specification, a pooled "yoga effect" averages unlike things, and replication becomes impossible [87].

7.4 Mechanism claims that outrun their designs

The most widely repeated mechanistic claims are supported by the thinnest designs. The GABA story rests on a pilot study of experienced practitioners and a 34-person randomised study using correlational links [65,78]. The inflammation story rests heavily on a cross-sectional comparison in which the single yoga session had no distinctive inflammatory effect [66], supplemented by small randomised pilots [80,81] and an uncontrolled retreat study [82]. The telomere story depends on small, multicomponent or uncontrolled studies [85,86]. Brain-structure findings are mostly cross-sectional or small before-and-after designs [68,69,79]. Polyvagal accounts rest on a theory whose physiological premises are disputed [75,77]. Mechanistic language such as "yoga activates the vagus nerve" or "yoga reverses ageing" therefore communicates far more certainty than the evidence supports.

7.5 Confounding, self-selection and the healthy-practitioner problem

Many mechanistic findings arise from comparing practitioners with non-practitioners or experts with novices [66,69,79]. People who persist in yoga differ in ways that are not randomly distributed: they are more often women and more often highly educated [2,63], and they may differ in diet, sleep, physical activity, social support and health-seeking behaviour, any of which can influence inflammatory markers, pain tolerance or brain structure. Statistical adjustment can reduce but not eliminate such

confounding. Reverse causation is also plausible, since people with lower stress reactivity or better baseline health may find it easier to sustain a regular practice. Cross-sectional contrasts are therefore hypothesis-generating at best, and their frequent presentation in popular media as proof that yoga "changes the brain" or "lowers inflammation" reflects a failure to respect the limits of the design.

7.6 Dose, adherence and durability

Trials of yoga rarely identify a minimum effective dose, and programmes range from a handful of weeks to several months with widely varying session frequency and home practice [88,89]. Adherence is seldom reported in a way that links practice time with outcome, which prevents dose–response analysis, one of the classical criteria for causal inference. Durability is equally uncertain: the depression meta-analysis could not pool long-term effects [14], and the meditation review found smaller benefits at three to six months than at eight weeks for anxiety (0.38 falling to 0.22) and depression (0.30 falling to 0.23) [54]. An intervention whose benefits attenuate after the programme ends has different clinical and public-health implications from one whose benefits persist.

7.7 Reproducibility and the structural vulnerability of small-trial fields

General meta-research reveals why caution is warranted. Ioannidis argued that research findings are less likely to be true when studies are small, effect sizes are modest, designs and outcomes are flexible and there are strong interests or prejudices in a field [90]. Several of these conditions are common in contemplative-science research. The Open Science Collaboration attempted to replicate 100 published psychology studies and found that 97% of the originals reported significant results whereas only 36% of replications did, with replication effects on average about half the original magnitude [91]. Although yoga trials were not the target of that project, the lesson on inflated effects in small, flexible studies applies. Critics of the mindfulness literature have made similar arguments about measurement, definitions and overinterpretation [56].

7.8 Reporting gaps and publication bias

The randomised-trial safety review found that adverse events were inconsistently reported [60], and the depression review found no trial reporting safety data [14]. Incomplete harm reporting inflates the apparent benefit-to-risk ratio. The same logic applies to selective outcome reporting and to publication bias, both of which are difficult to rule out in a field of small, positively framed studies [37,39].

7.9 Safety and the myth of benign practice

The adverse-event literature disrupts the assumption that yoga is inherently harmless. Case reports show injuries concentrated in particular postures and breath practices and in vulnerable persons [59], and the trial-level evidence suggests risk is comparable to that of other exercise rather than negligible [60]. Meditation-related challenges, including distressing experiences, have been documented in qualitative and mixed-methods work [61,62]. A responsible scientific reinterpretation of yoga must therefore include adverse-event monitoring, informed screening of participants and teacher training, rather than treating safety as an afterthought. Health-system integration of yoga therapy would, moreover, need to sit within the patient-safety governance already applied to clinical interventions in hospital settings [92].

7.10 Decontextualisation and commodification

Finally, the translation can distort the object it studies. Historical research shows that modern postural practice is partly a twentieth-century hybrid [5,6], that scientific legitimization was part of a nationalist and reformist project [31] and that global markets have shaped what yoga means in everyday life [33,34]. When trials extract posture or breath from the ethical, linguistic and relational framework within which the traditions situate them, they study a fragment. Sociological scholarship on language, ritual formation and culture warns that practices acquire meaning through repetition within a social milieu [19-21], and clinical protocols seldom capture that milieu. This is not an argument against studying fragments, only for naming them accurately.

7.11 The authenticity paradox

The demand for "authentic" yoga research sets two purisms against each other. Textual purism treats the sutras or the hatha manuals as normative and judges modern practice as deviation, yet history shows that these sources are themselves layered and that their influence was uneven [4,29]. Scientific purism treats randomised evidence as the only legitimate warrant, yet such designs cannot test ontological or soteriological claims. Authentic research on yoga is best defined not by fidelity to one source of authority but by transparent alignment among four elements: a declared textual or lineage reference, a specified intervention, an outcome measure that matches the construct claimed and an honest statement of what the design can and cannot show.

8. Analysis from Different Perspectives

8.1 The historian-philologist

For the philologist, the primary question is what a term meant in its textual setting. White's biography of the Yoga Sutra and Maas's historiography caution against reading the text as a timeless manual and show how its status changed over time [4,25]. Singleton's work demonstrates that the postural practice most studied in trials is a modern formation [5]. From this perspective, "ancient yoga confirmed by science" is a category error whenever the practice under test is of recent origin.

8.2 The clinician-epidemiologist

The clinician asks whether yoga helps patients, by how much and compared with what. The answer is moderate and conditional: small short-term benefits against inactive controls, similar effects to other exercise, low-to-moderate certainty and a safety profile comparable to other activity [15,16,60]. For this perspective, authentic research means adequately powered, pre-specified trials with active comparators, harm reporting and long follow-up [37,39].

8.3 The neuroscientist

The neuroscientist seeks mechanisms and proposes integrative frameworks that combine top-down and bottom-up pathways [67]. The same community is also the source of the most pointed internal critique, which argues for clearer definitions, better controls and the replacement of promissory language with testable hypotheses [56]. Authentic research here means mechanistic claims matched to designs capable of testing them.

8.4 The sociologist and postcolonial critic

The sociologist reads yoga as a social fact. Historical sociology shows how yoga became a transnational commodity and a site of identity formation [33,34], and how scientific legitimization was entangled with nation-building [31]. Indian sociological scholarship on language, *samskāra* and culture underscores that values are transmitted through social structures, not by techniques alone [19-21]. For this perspective authentic research must examine who practises, who is excluded and who profits, and must treat meaning as data. Survey evidence that practice is concentrated among women and more educated adults [2,63] is therefore itself a research finding, not merely a descriptive background.

8.5 The practitioner and lineage holder

The practitioner values transmission within a lineage, an integrated discipline and ethical commitment. Teacher-led systematisation, as in Iyengar's codification of postures, shows how a lineage can organise practice with considerable precision [32], while historical work on source texts shows how diverse the lineages are [8,29]. From this perspective, research that measures a thirty-minute class as "yoga" captures little of the practice as lived; authentic research must include long-term practitioners and the ethical dimension that Gandhian and classical sources both place at the centre [22,23].

8.6 The institutional and policy perspective

Educational and health institutions require measurable, auditable outcomes. In Indian higher education, quality assurance and accreditation have been analysed extensively, including the role of outcome-based approaches and the linkage between assessment processes and learning outcomes [93-100]. Any expansion of yoga curricula within such a system would be evaluated within these frameworks, which favour defined outcomes, indicators and documentation. That pressure is double-edged: it can promote rigorous specification of yoga courses, but it can also reduce yoga to what is countable. The research agenda below is designed to preserve both rigour and meaning.

8.7 Convergence and divergence across perspectives

Although the six perspectives differ, they converge on three points. All agree that "yoga" cannot be treated as a single, stable object: the philologist shows it to be layered, the clinician finds heterogeneous interventions, the sociologist finds it commodified and the practitioner finds it lineage-specific [4,29,33,89]. All agree that stronger claims require stronger warrants, though they disagree about what counts as one: a textual source, a randomised trial, a mechanistic correlate, a social analysis or lived experience. And all acknowledge that measurement changes what is measured. They diverge sharply on whether scientific translation is a gain or a loss. Optimists see a bridge that gives a traditional practice public legitimacy and a route into health systems [1,31]; critics see a reduction that detaches technique from ethics and meaning [33,34]. This paper takes the position that both observations can be true at once, and that the task for research is to make the trade-offs visible rather than to deny them.

9. Implications and Research Agenda

Four implications follow. First, claims for yoga in clinical and public-health communication should be calibrated to the evidence: modest, short-term benefits for depressive symptoms, blood pressure and back pain, with low-to-moderate certainty, and equivalence to other active options [14-16]. Second, mechanistic claims should be presented as hypotheses unless supported by randomised, adequately powered, preferably pre-registered designs [90,91].

Third, studies should specify interventions with enough detail to allow replication, using established reporting guidance for interventions and yoga-specific recommendations [87-89], and should include active and, where feasible, attention-matched comparators to isolate specific effects [15]. Fourth, safety monitoring should be routine, including systematic collection of adverse events and screening for vulnerable participants [59,60,62].

Beyond these, five lines of inquiry deserve priority. (a) Long-term randomised trials that follow outcomes beyond the typical short window identified as a limitation in existing reviews [14,16]. (b) Mixed-methods studies that integrate physiological outcomes with practitioners' interpretive frameworks, so that meaning is analysed alongside measurement [58,67]. (c) Studies of ethical-limb constructs and social formation, drawing on Indian moral and sociological scholarship [19-23]. (d) Comparative studies of yoga and meditation that specify techniques and frameworks, not merely outcomes [56,57]. (e) Equity-oriented research on who gains access to yoga and who benefits, informed by survey evidence on unequal uptake [2,63].

A practical consequence is a minimum reporting standard for future yoga studies. Each report should state the lineage or textual reference from which the practice derives; the style, components and sequence of postures, breathing and meditation; the dose, including session length, frequency, duration and home practice; the qualifications of the teacher; the comparator and its rationale; the measures of adherence; the adverse events, including those that were not serious; and the extent to which the construct measured corresponds to the construct claimed [87-89]. Such a standard turns the abstract ideal of authenticity into a checklist that editors, reviewers and readers can apply.

10. Limitations

This synthesis has limitations that should temper its conclusions. The external evidence was selected purposively and not through an exhaustive multi-database search, so some relevant studies are certainly absent, and the review makes no claim to completeness. The date rule restricting sources to 2024 or earlier means that more recent trials and reviews are not represented. Appraisal relied substantially on the original authors' risk-of-bias and certainty judgements rather than on full independent re-appraisal. Effect sizes were deliberately not pooled, so the comparative analysis is qualitative and illustrative. English-language sources dominate, with the exception of Hindi-language sociological titles whose content was used only for general contextual claims about language, ritual and culture. Finally, the topic spans historical, biomedical and sociological literatures with incompatible standards of evidence, and the integration offered here is interpretive.

11. Conclusion

The journey from sutra to science is real but is not a straight line. Philological scholarship shows that the sutras, the haṭha manuals and modern postural yoga are distinct layers with different aims, and that the practice most often studied in trials is substantially modern [4,5,26]. Scientific evidence available up to 2024 supports a modest, conditional case for yoga as a low-risk, low-cost intervention for depressive symptoms, cardiometabolic risk markers and chronic low back pain, with effects usually comparable to those of other active interventions [11,14-16]. It supports far less certainty for the mechanistic narratives that dominate public discussion, and nothing at all for the anatomical claims of

the subtle body or the soteriological claims of the sutras, which lie outside the reach of such designs [28,65,66,85].

The most defensible modern lens on yoga is therefore translational without being reductive. It treats breath, posture and attention as trainable skills with measurable correlates; it insists on specification, comparators, long follow-up and safety reporting; and it recognises that yoga is also a transmitted, ethically framed cultural practice whose meanings are not fully captured by biomarkers [19-23]. Research that honours both registers, rigorous in method and literate in tradition, is the form of authenticity most likely to endure.

For readers, editors and clinicians, the practical message is plain. Yoga can be offered as a reasonable, low-risk option alongside other forms of structured activity, provided that its limits are acknowledged and harms are monitored. For researchers, the message is that the next decade's contribution lies not in more small, positive studies but in fewer, better ones, designed with textual literacy, methodological discipline and cultural humility. In that sense, the movement from sutra to science will be complete only when science has learned to read the sutras as carefully as it measures the breath.

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