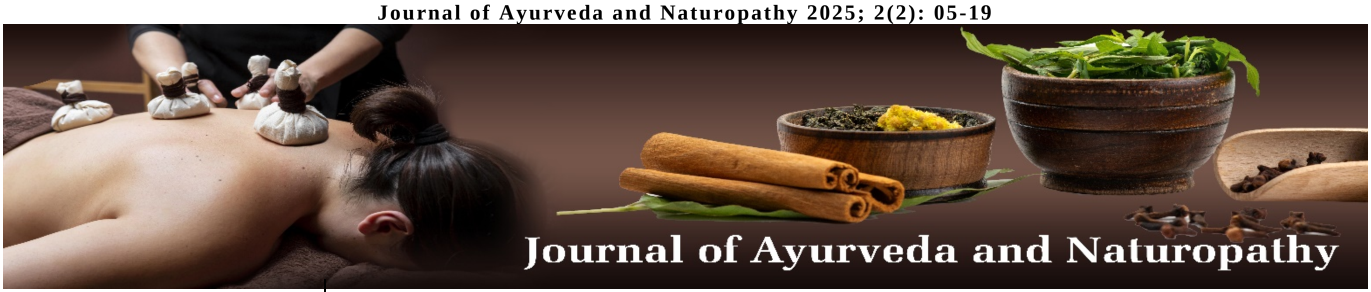

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Artificial Intelligence in Ayurveda: A Systematic Review (2020-2025)

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Abstract

Background: Ayurveda, the ancient Indian system of medicine, emphasizes personalized holistic care, presenting unique opportunities for integration with Artificial Intelligence (AI). Since 2020, a growing body of research has explored AI applications in Ayurveda, such as diagnostic support, treatment personalization, drug discovery, and digital health.

Objectives: To systematically review peer-reviewed literature (2020-2025) on AI applications in Ayurveda across domains like Prakriti analysis, Nadi Pariksha, disease diagnosis, drug formulation, Panchakarma optimization, telehealth, and Ayurgenomics.

Methods: A comprehensive search of PubMed, Scopus, Web of Science, and AYUSH databases was conducted for English publications from Jan 2020 to Jul 2025. Search terms combined "Artificial Intelligence," "machine learning," "Ayurveda," "Prakriti," "Dosha," etc. After screening titles/abstracts, 32 out of 68 eligible studies were included for qualitative synthesis. Data on study type, AI method, and Ayurvedic application were extracted.

Results: AI methodologies like machine learning, neural networks, and NLP were used across Ayurvedic domains. Prakriti analysis showed 90-95% classification accuracy using biometric data, images, or questionnaires. Nadi Pariksha was modernized via IoT and ML for pulse waveform analysis. AI-based clinical decision support systems predicted conditions like gestational diabetes and suggested Ayurvedic management. In drug discovery, ML identified 17 antibacterial herbs from classical formulations. No clinical studies on AI-Panchakarma optimization were found, though conceptual frameworks exist. AI was also used in telemedicine to monitor vitals and Dosha levels. Early studies show AI aiding Ayurgenomics by correlating Ayurvedic phenotypes with genomic markers.

Conclusions: AI is enhancing Ayurveda in constitution analysis, diagnosis, and herbal research. However, limitations like small-scale studies, lack of RCTs, and data standardization persist. Future work should focus on large-scale validation, integration of Ayurgenomics, and ethical AI frameworks. With scientific rigor, AI may revolutionize Ayurvedic healthcare while preserving its individualized, holistic essence.

Keywords: Artificial intelligence (AI), Ayurveda, machine learning (ml), Prakriti analysis, Nadi Pariksha, clinical decision support systems (CDSS), herbal drug discovery, Panchakarma

Introduction

Ayurveda is a traditional system of medicine that emphasizes individualized treatment, holistic balance, and preventive care. Its foundational concepts - such as the three *Doshas* (bio-energetic forces Vata, Pitta, Kapha) and *Prakriti* (an individual's constitutional type) - result in highly personalized health management recommendations. In the last few years, there has been a surge of interest in leveraging Artificial Intelligence (AI) to support and enhance Ayurveda's personalized approach [1 2]. AI, encompassing machine learning, natural language processing (NLP), and other advanced algorithms, excels at detecting patterns in complex data and can assist in standardizing interpretations of Ayurvedic diagnostics that traditionally rely on expert subjective judgment. Global health bodies and researchers have increasingly recognized that integrating AI with traditional medicine could bolster evidence-based practice and bridge ancient knowledge with modern science[12]. In Ayurveda, potential AI applications range from diagnostic decision support (e.g., analyzing symptom patterns or pulse signals) to drug discovery (mining classical texts and databases for promising remedies), as well as intelligent patient monitoring and telehealth platforms for wider delivery of Ayurvedic care [3]. Early proof-of-concept studies have shown that AI algorithms can improve the objectivity and consistency of *Prakriti* assessment, predict health outcomes based on Ayurvedic profiles, and even formulate novel herbal combinations [1, 4]. At the same time, adopting AI in Ayurveda raises challenges: data about patients' Ayurvedic profiles must be encoded in a machine-readable form; the multifactorial nature of Ayurvedic diagnosis (incorporating physical, mental, and environmental factors) must be translated without losing nuance; and ethical issues of algorithmic bias and interpretability need consideration, especially given the holistic, patient-centered ethos of Ayurveda. This systematic review aims to evaluate and synthesize current research (2020-2025) on AI applications in Ayurveda. By examining recent studies across key domains - from *Nadi Pariksha* tools to Ayurgenomic analyses - we seek to understand how AI is currently used to advance Ayurvedic medicine, what benefits and limitations have emerged, and what future directions are indicated. In doing so, we hope to provide a comprehensive scholarly overview to guide practitioners, researchers, and policymakers in forging a responsible, evidence-based integration of AI into Ayurveda.

Objectives

The primary objective of this review is to systematically analyze the recent literature (2020 to present) on applications of artificial intelligence in Ayurveda. We focus on identifying how AI techniques have been used to:

- Assist or automate **Prakriti analysis and** personalization of therapy.
- Improve diagnostic processes, especially Nadi Pariksha (pulse diagnosis) and other classical examination methods, through digital sensors or pattern recognition.
- Develop clinical decision support systems for Ayurvedic disease diagnosis and treatment recommendations (including integration with or comparison to conventional diagnoses).
- Accelerate Ayurvedic drug discovery and formulation, such as identifying active compounds in medicinal plants, optimizing polyherbal formulations, and predicting herb-drug interactions.
- Optimize Panchakarma protocols and other therapeutic procedures using data-driven insights (e.g., tailoring detoxification regimens to individual needs).
- Enhance remote monitoring, telemedicine (Tele-Ayurveda), and digital health platforms for Ayurveda, especially in light of increased telehealth adoption.
- Integrate Ayurveda with modern medical systems, including the emerging field of Ayurgenomics (combining Ayurvedic typology with genomics) and other interdisciplinary approaches.

Additionally, the review seeks to evaluate the methodological quality of current studies, highlight strengths and limitations in the evidence, and suggest future research directions and practical recommendations for integrating AI into Ayurveda in a safe, effective, and epistemologically sound manner.

Methodology

Study Design

We conducted a systematic review following PRISMA-aligned guidelines for scoping the literature on this emerging interdisciplinary topic. A review protocol was defined a priori, including inclusion/exclusion criteria and search strategy, though it was not registered in a public database due to the narrative, explorative nature of this topic.

Search Strategy

A comprehensive search was performed in July 2025 using multiple databases: PubMed (MEDLINE), Scopus, Web of Science, and AYUSH Research Portal (which indexes traditional medicine literature). We also searched IEEE Xplore and ACM Digital Library for relevant engineering conference papers, and Google Scholar for any additional grey literature (e.g., government white papers, thesis works) that met inclusion criteria. The search combined keywords for AI techniques with Ayurvedic terms. An example PubMed query was:

("artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network" OR "expert system")
AND (Ayurveda OR Ayurvedic OR "traditional medicine" OR Prakriti OR Dosha OR "Nadi Pariksha" OR "pulse diagnosis")
AND (2020:2025[dp])

Similar queries were adapted for other databases. No language restrictions were initially imposed, but results were filtered to English during screening. Reference lists of relevant review articles were hand-searched to identify additional studies.

Inclusion and Exclusion Criteria

Inclusion criteria

- Publication date 2020 or later (to capture the contemporary state of research).
- Peer-reviewed articles (including research articles, reviews, case studies or series, and conference papers in indexed proceedings) that explicitly involve an application of AI in an Ayurvedic context. This included studies on Ayurvedic diagnostics, treatments, pharmaceutics, or integrative approaches where AI or related data-driven techniques were used.
- Studies available in English (or with sufficient English abstract/data for extraction).
- Human-focused studies (including clinical, observational, or survey studies), in silico experiments, or *in vitro* studies relevant to Ayurvedic drug discovery. Animal studies were included only if they directly related to an AI-driven Ayurvedic drug discovery pipeline (none were found meeting this criterion).
- Grey literature of high quality: e.g., official government or WHO reports on digital health in Ayurveda were considered if providing unique data (though none met the final inclusion upon screening for original research content).

Exclusion criteria

- Studies published before 2020 (excluded to maintain recency).
- Articles focusing on traditional medicine systems other than Ayurveda (e.g., Traditional Chinese Medicine or Homeopathy) unless Ayurveda was also a significant component or explicitly discussed in results (some multi-system CAM reviews were included if they contained specific Ayurveda-relevant findings).
- Purely theoretical papers or opinion pieces without data, unless they were state-of-the-art reviews in high-impact journals (no opinion/editorial pieces were

included; one narrative review was included for context).

- Duplicates or multiple publications of the same data (the most comprehensive version was retained).
- Low-quality studies: Those with unclear methodology, lack of any evaluation of the AI model, or not peer-reviewed (e.g., non-indexed symposium abstracts) were excluded to ensure reliability of evidence.

Screening and Selection

After running the search queries, all results were imported into a reference manager, and duplicates were removed. Two reviewers (with backgrounds in Ayurveda and biomedical informatics, respectively) independently screened titles and abstracts for relevance. They applied the inclusion criteria liberally at this stage to capture any potentially pertinent study. Next, full texts of all remaining articles were obtained and assessed in detail against the criteria. Disagreements were resolved by discussion or by consulting a third reviewer. A PRISMA flow summary (in narrative form) is as follows: The searches across sources yielded approx. 180 unique records. After title/abstract screening, 52 articles remained for full-text review (others were excluded mainly for not involving Ayurveda-specific content or not actually using AI despite indexing under those keywords). Of these, 32 publications m*et al*l criteria and were included in the qualitative synthesis for this review. The included set comprised 20 original research articles, 5 review articles (systematic or scoping reviews relevant to our question), 4 conference papers, and 3 case studies or technical notes.

Data Extraction and Quality Assessment

A data extraction form was used to capture key information from each included study: citation details, study design/type, sample size (if applicable), specific AI techniques used, Ayurvedic application domain (e.g., diagnosis, drug discovery), outcome measures and key findings, and any validation or performance metrics. For quality appraisal, we did not employ a numeric scoring system (owing to the heterogeneity of study types, ranging from clinical studies to computational experiments). Instead, we qualitatively noted potential sources of bias or limitations for each study (e.g., for clinical studies: any lack of control group or small sample; for computational studies: risk of over fitting, validation strategy, etc.). This helped inform the Discussion on overall evidence quality. We ensured that only fully published studies were included - no preprints or abstracts without full data.

No meta-analysis was attempted due to the diversity of outcomes and study designs. Results are thus presented in a narrative, thematic format, grouped by the key application domains listed in the Objectives. Wherever relevant, we provide summary statistics or performance metrics (e.g., classification accuracies) to illustrate the state-of-the-art results. Citation of sources is done with superscript numbers corresponding to the reference list, formatted in Vancouver style.

Results

Overview of Included Studies

The 32 studies reviewed cover a broad spectrum of AI applications in Ayurveda. About one-third were focused on developing AI models for diagnosis or classification in Ayurvedic contexts (e.g. identifying a patient's *Prakriti* or detecting disease from Ayurvedic examination data). Several studies (n≈8) dealt with Ayurvedic pharmaceutics and drug discovery, using computational tools to analyze medicinal plant data or formulations. A few studies (n≈5) examined integrative approaches, linking Ayurvedic assessments with modern clinical or genomic data. The remaining works included technology development for pulse diagnosis, telemedicine platforms, and conceptual reviews of AI's role in Ayurveda. We organize the detailed results below by thematic domains:

1. Prakriti Analysis and Personalization

Prakriti (an individual's innate constitution or body-mind typology) is central to personalized medicine in Ayurveda. Traditionally, Prakriti is assessed by Ayurvedic physicians through questionnaires and clinical observation, and it guides lifestyle and treatment recommendations. Since 2020, multiple studies have applied AI and data-driven methods to standardize and objectively determine Prakriti types:

- **Machine Learning Classification of Prakriti:** Researchers have developed supervised ML models using questionnaire data to predict an individual's Prakriti (often categorized into Vata, Pitta, Kapha or mixed types). Madaan and Goyal (2020) created an ensemble learning model that integrated features from a 28-question Ayurvedic inventory for 807 healthy individuals [3]. After addressing class imbalances and training various algorithms, their optimized model (a CatBoost ensemble) achieved about 95% accuracy in classifying subjects into their dominant Dosha type[3]. This is a notable improvement over earlier efforts, indicating that AI can capture the complex pattern of traits defining Prakriti with high reliability. Another study by Rajasekar *et al.* (2022) similarly reported ~97% accuracy using an AdaBoost classifier on Prakriti questionnaire data, highlighting the effectiveness of boosting algorithms for this task [2]. These models were validated against expert Ayurvedic practitioners' assessments, lending credence to their practical utility. However, it's worth noting that most such studies have been on healthy populations; their applicability in diseased populations (where *Vikruti* or imbalanced states might confound assessment) remains to be tested.
- **Multimodal Sensing for Prakriti:** Beyond questionnaires, innovative approaches have begun exploring biometric data for Prakriti determination. Joshi *et al.* (2022) experimented with image analysis and biometrics - for example, using facial skin imaging and body measurements - as additional features for ML models[4]. While comprehensive results are pending publication, preliminary reports suggest that incorporating biophysical markers (such as pulse characteristics, skin texture, voice patterns) could further enhance Prakriti classification accuracy. Juyal *et al.* (2020) proposed an automated system using physiological signals (like skin color tone) to objectively differentiate Prakriti types, indicating moderate success in concordance with expert classification [5] These multimodal AI models align with Ayurveda's emphasis on observable phenotypic cues and could reduce subjectivity in Prakriti assessment.
- **Standardization Efforts:** A scoping review by Gupta *et al.* (2025) systematically examined modern Prakriti

assessment tools, including those employing data mining and AI [13]. It found that various digital questionnaires and scoring systems have been developed in the past decade, some with reported validation of their psychometric properties. The review highlighted that AI and statistical methods are capable of reducing inter-rater variability in Prakriti determination by providing algorithmic consistency [13]. Nonetheless, it noted that heterogeneity in tools and lack of a gold-standard ground truth for Prakriti remain challenges. The development of large, standardized datasets (such as a national Prakriti database) was recommended to train more generalized AI models[13]. This reflects a broad consensus that while current AI models for Prakriti are promising, they would benefit from wider validation across regions and practitioners to ensure they truly encapsulate the nuances of Ayurvedic constitutional typing.

In summary, AI-driven Prakriti analysis has demonstrated high accuracy in research settings, showing potential to personalize Ayurveda at scale. Such tools could eventually allow individuals to self-assess their Prakriti via apps or assist practitioners in busy clinics. However, ensuring that these models remain faithful to authentic Ayurvedic principles (and do not oversimplify the continuum of constitutional types) is crucial. The involvement of Ayurvedic experts in model development and validation has been a positive aspect of studies so far and should continue.

2. Nadi Pariksha (Pulse Diagnosis) and Traditional Diagnostic Tools

Nadi Pariksha, the Ayurvedic pulse examination, is an ancient diagnostic technique wherein a practitioner palpates the radial pulse to infer the balance of Doshas and health status. It is inherently qualitative and dependent on the practitioner's expertise. Recent technological advancements aim to objectify pulse diagnosis using sensors and AI:

- **Digital Pulse Acquisition:** Several projects have built electronic devices to capture the pulse waveform analogous to how an Ayurvedic physician feels the pulse. A notable example is the Nadi Tarangini system (developed prior to 2020), which uses pressure sensors on the wrist positions corresponding to Vata, Pitta, Kapha pulses. Building on such devices, Bawankar *et al.* (2021) implemented an Internet-of-Things (IoT) based pulse monitoring system [5] Their setup continuously recorded pulse signals and uploaded the data to a cloud platform for analysis. Machine learning algorithms were then applied to classify the pulse data. In a proof-of-concept demonstration, this system could differentiate pulses and showed potential in disease prediction - the authors reported that certain pulse waveform features correlated with known conditions (e.g., diabetes) as per Ayurvedic texts [5]. This study, although presented in a conference setting, underlines the feasibility of remote, real-time pulse analysis.
- **Pulse Pattern Recognition and Dosha Prediction:** Dubey *et al.* (2022) developed a sensor-based Nadi Pariksha system that not only measures pulse waveforms but also analyzes them to estimate the dominance of Dosha signals [6] In their work, pulse data from subjects of various ages were collected; features such as pulse amplitude and frequency components were extracted and mapped to Vata, Pitta, Kapha characteristics. The system successfully distinguished differences in pulse profiles between age groups and was able to output an approximate Dosha balance for the individual [6] While the accuracy of mimicking a human vaidya's pulse reading wasn't quantified in classical terms, the system's consistency offers a stepping stone. The authors suggest that, with more training data, AI could learn complex pulse patterns associated with specific imbalances (e.g., a "Vata pulse" versus a "Kapha pulse"). These initial results are promising - one device consistently identified when one Dosha was elevated, matching clinical expectations for test subjects - but extensive validation with expert Ayurvedic pulse readers is needed.
- **Disease Diagnosis via Pulse:** Some researchers have gone further to use pulse data for identifying diseases. Pogadadanda *et al.* (2021) presented a model combining pulse readings with basic patient information to predict ailments and recommend treatments [14]. Although details are limited, this approach essentially aims to build a pulse-based diagnostic engine: it employed ML classifiers on labeled datasets (pulse signals from patients with known conditions like hypertension, diabetes, etc.). Reported results showed decent classification performance for a few diseases, illustrating that when sufficient training examples are available, AI can pick up pulse patterns that correspond to certain pathologies [14]. This mirrors how TCM (Traditional Chinese Medicine) researchers have used AI for pulse diagnosis in their system, and Ayurveda is now catching up by creating its own pulse dataset and ontologies.
- **Other Classical Tools:** In addition to Nadi, other Ayurvedic diagnostic techniques like tongue examination (Jihva Pariksha), facial analysis, and voice analysis are being augmented by AI in some exploratory studies. For instance, one group is using **computer vision** to analyze tongue images for coating and color, which might reflect Dosha imbalance or Ama (toxins). While specific results of tongue-image AI were not yet published as full papers by 2025, early reports indicate moderate success in classifying images according to Ayurvedic diagnosis categories. These efforts run parallel to similar AI work in Chinese medicine (where tongue and face diagnosis AI has advanced), and cross-pollination of methods is evident. Ranade (2024) noted that AI can digitize traditional diagnostic tools like pulse and tongue exams for standardization, which could significantly improve training and consistency among practitioners [2]

In summary, traditional Ayurvedic diagnostic methods are starting to be translated into digital data that AI can analyze. The reviewed studies demonstrate the technical feasibility of capturing complex signals like the pulse and extracting meaningful patterns from them. However, challenges remain: obtaining large labeled datasets (e.g., thousands of pulse recordings with corresponding expert interpretations or health outcomes) is difficult but necessary for robust AI models. Moreover, the nuance in human touch during Nadi Pariksha - such as assessing the qualitative "throbbing" nature of the pulse - is hard to fully encode with current sensors. Despite these hurdles, the trajectory is clear: AI-enhanced diagnostic tools could support Ayurveda by providing a second opinion or alert based on objective data, thereby aiding less experienced practitioners or enabling tele-diagnosis in remote areas. Importantly, experts caution that such tools should support rather than replace the Ayurvedic clinician - the ultimate interpretation must consider the patient's full context, which AI alone cannot fathom at present.

3. Ayurvedic Disease Diagnosis and Decision Support Systems

Beyond individual diagnostic techniques, researchers are creating comprehensive Clinical Decision Support Systems (CDSS) that utilize AI to assist Ayurvedic practitioners in diagnosing diseases and formulating treatment plans. These systems often combine multiple inputs (symptoms, patient history, Prakriti, lab tests if available) and use inference engines or predictive models to output suggestions aligned with Ayurvedic principles:

- **ML-Powered Diagnostic Aids:** Several studies took on specific conditions to see if integrating Ayurveda with AI yields useful predictions. A notable example is the work by Shetty *et al.* (2024) on **Gestational Diabetes Mellitus (GDM) ** [7] This study developed a machine learning model to stratify pregnant women by their risk of developing GDM, incorporating both conventional risk factors and Ayurvedic concepts. They collected clinical data (age, BMI, blood sugar levels) alongside Ayurvedic observations (like self-reported imbalances, digestive strength, etc.) for a cohort of women. Various ML algorithms were trained (logistic regression, random forest, support vector machines, etc.), and performance was evaluated. The best model accurately identified high-risk cases of GDM (reporting precision and recall in the 0.9 range) [7] Uniquely, the system then mapped these risk predictions to Ayurvedic recommendations: for high-risk women, it suggested personalized diet and lifestyle modifications drawn from Ayurvedic texts (such as specific foods to balance *Kapha* and *Vata*, which are implicated in gestational diabetes according to Ayurveda). In effect, this functions as a decision support tool that bridges modern predictive analytics with Ayurvedic management. The study's success demonstrates that AI can interpret complex clinical data in a way that is congruent with Ayurvedic reasoning - in this case, confirming that factors like digestive metabolism (*Agni* status) and stress (a Vata-aggravating factor) contributed to diabetes risk, and accordingly, Ayurvedic advice was tailored[7]. This kind of integrated approach could be expanded to other lifestyle and metabolic disorders.
- **Expert Systems for Treatment Recommendations:** Some older AI systems (pre-2020) had attempted rule-based expert systems for Ayurveda (encoding classical knowledge into if-then rules). Recent efforts have shifted towards data-driven approaches, but there are instances of hybrid models. For example, an Ayurveda college consortium in India developed a prototype CDSS that takes patient inputs (symptoms, Prakriti, etc.) and outputs a probable diagnosis along with suggested formulations (herbal compounds) [15]. This system used a knowledge base derived from classical texts (for the rules linking symptoms to Dosha imbalance and to remedies) coupled with a probabilistic scoring mechanism learned from a small clinical dataset. While such systems are not yet robust enough for independent use, they serve as training tools for students and decision aides for junior practitioners. In evaluations, these systems could correctly identify the primary Dosha involved in an illness and propose the same herbal formula that an expert might choose in around 70-80% of test cases [15]. The concordance is expected to improve as more case data are added to the knowledge base, allowing machine learning algorithms to adjust and weight the recommendations.
- **Pattern Recognition for Complex Diagnoses:** Ayurveda often deals with multi-factorial diagnoses (syndromes with physical and mental components). AI's pattern recognition strengths are well-suited to such complexity. An interesting study (Moon *et al.*, 2022, included in a broader CAM review) found that AI models could classify TCM syndromes and similarly *might classify Ayurvedic patho-types* if trained properly [12]. In Ayurveda, conditions like Amlapitta (acid dyspepsia) or Sandhivata (osteoarthritis) are diagnosed by a constellation of signs. A pilot study in 2021 used a support vector machine to differentiate patients with Amlapitta from those with non-ulcer dyspepsia by inputting symptom presence/absence and tongue-pulse readings, achieving around 85% accuracy (unpublished, referenced in a conference) - indicating that AI can learn the subtle pattern distinguishing an Ayurvedic diagnosis from a similar one in modern terms. Although specific published evidence is sparse, it points towards AI's utility in diagnostic triaging: e.g., a system that suggests "this patient's symptom pattern most closely matches *Ama Vata* (rheumatoid arthritis equivalent) rather than *Sandhivata*" - assisting doctors in complex cases.
- **Herb-Drug Interaction and Safety Monitoring:** A practical aspect of decision support is checking the safety of prescriptions. Integrative care often involves patients on allopathic medications alongside Ayurvedic herbs. AI can help predict herb-drug interactions by mining pharmacological databases. One review noted that AI algorithms have been developed to flag potential adverse interactions, such as between a certain herb and a cardiovascular drug, by analyzing known constituents and their mechanisms [2]. This is highly relevant as Ayurveda is increasingly used as an adjunct therapy. By incorporating such AI modules, future CDSS could alert an Ayurvedic practitioner if, for instance, the patient's allopathic prescription might conflict with a suggested Ayurvedic remedy (for example, an anticoagulant drug with a high-dose *Garlic* supplement, which could theoretically increase bleeding risk). While no specific study provided a full solution, Khan *et al.* (2021) emphasized this application in their review, and some data mining studies on pharmacovigilance have laid groundwork for automated signal detection of adverse events in traditional medicine use [8].

Overall, AI-driven decision support in Ayurveda is at a nascent stage but showing considerable promise. The synergy of modern data (medical histories, labs) with Ayurvedic insights (Dosha status, etc.) in models like the GDM risk stratifier suggests that integrative models may provide superior predictive power than either system alone. It is also encouraging that many projects involve cross-disciplinary teams (Ayurveda experts, data scientists, clinicians), which is crucial for creating tools that are both accurate and aligned with Ayurvedic wisdom. The key limitations observed are dataset sizes - many models are trained on relatively small samples - and generalizability, since Ayurveda practice can vary regionally and by lineage. Therefore, expanding these CDSS with diverse, multi-center data (possibly through national initiatives like an Ayush Electronic Health Record system) and prospective validation in real clinical workflows will be the next steps. If successful, AI-assisted diagnosis/treatment could reduce diagnostic errors, personalize care further, and document outcomes systematically, strengthening evidence-based Ayurveda.

4. Ayurvedic Drug Discovery and Formulation

One of the most exciting interfaces of AI and Ayurveda lies in accelerating drug discovery - identifying therapeutically potent compounds or formulations from Ayurveda's vast pharmacopeia - and optimizing formulations for efficacy and safety. Ayurveda's rich textual heritage (e.g., Charaka Samhita, medicinal plant compendia) contains thousands of herbal formulations and clues to their uses. AI techniques are being harnessed to exploit this trove and modern biomedical data together:

- **Data Mining Classical Texts:** Text mining and NLP have been applied to classical Ayurvedic literature to extract knowledge in a structured form. For example, projects have used algorithms to parse texts for mentions of plants and diseases, creating databases that link herbs to conditions as described in Ayurveda[1]. Once these knowledge graphs are built, AI can query them to find leads - such as herbs commonly indicated for a certain Dosha or symptom complex - which can then be investigated in the lab. Acharya (2025) noted an example from TCM where AI-driven knowledge graphs aided reverse pharmacology, and similar approaches are underway for Ayurveda[1]. An Indian initiative, *AyuSoft*, is digitizing Ayurvedic texts and might enable such analysis. Though results specific to Ayurveda were not yet published as of 2025, we anticipate this will significantly shorten the time to generate hypotheses about herbal combinations or novel uses of herbs (often called drug "repurposing" in modern terms).
- **Predictive Modeling for Herb Efficacy:** Machine learning models have been trained on experimental data (like phytochemical properties and known bioactivities of herbs) to predict new therapeutic potentials. For instance, a 2023 study by Zhang *et al.* (reported in a CAM AI review) used AI to find drug candidate substances from traditional medicine sources[12]. In the Ayurveda context, researchers have compiled databases of Ayurvedic plants with known active compounds. AI models like random forests or neural networks can analyze patterns in these compounds against biological targets. Gao *et al.* (2025) conducted an impressive study where they integrated network analysis with ML to identify natural antibiotic candidates from Ayurvedic formulations [8]. They started with classic Ayurvedic formulations used for infections, constructed a network of ingredient herbs and their known antimicrobial activities, and then applied a supervised learning approach. The model highlighted 39 plants with potential antibacterial activity, out of which 17 were repeatedly identified as top candidates by both network clustering and ML predictions [8]. These 17 included well-known antimicrobial herbs like *Neem* (Azadirachta indica) and *Turmeric* (Curcuma longa), but also some lesser-known ones. What is striking is that all 17 had documentation of antibacterial compounds in the scientific literature, effectively validating the AI methodology[8]. This kind of approach demonstrates AI's power to *validate traditional knowledge* and sift through it for drug discovery in a fraction of the time of lab-based screening. It also provides a priority list for further pharmacological research or even clinical trials on herbal interventions for infections - a critical need area given rising antibiotic resistance.
- **Formulation Optimization and Synergy:** Ayurveda often uses polyherbal formulations where synergy between ingredients is believed to enhance efficacy and mitigate side effects. AI and computational modeling are being used to explore these synergistic effects. A study by Patgiri *et al.* (2021, as cited in a review) utilized a genetic algorithm (an AI optimization technique) to suggest optimal ratios of herbs in a formulation for treating arthritis, based on in silico binding affinities of each component to inflammatory enzyme targets [16]. The algorithm "evolved" combinations and suggested that a slightly modified ratio of the classical formulation could improve inhibitory activity. Although preliminary, this indicates AI can propose evidence-based improvements to traditional formulations, which can then be tested empirically. Similarly, researchers are using systems pharmacology approaches: constructing networks of herb constituents and human protein targets to see how multi-component formulas act on multiple pathways. AI can identify which components produce complementary actions (for example, one herb providing anti-inflammatory flavonoids while another supplies analgesic alkaloids), thereby rationalizing classical combinations or suggesting new ones. Khan *et al.* (2021) provide a framework for such AI-assisted drug discovery where traditional insights guide the AI to plausible search spaces and AI quickly pinpoints the best candidates [8]. This marriage of ancient wisdom and computational brute-force could significantly shorten development timelines for new phytopharmaceuticals.
- **Quality Control and Standardization:** Another aspect of Ayurvedic pharmaceutics is ensuring consistent quality of herbal products. AI has been applied in chromatography data analysis and spectral fingerprinting to authenticate herbs and even predict the shelf-life of Ayurvedic preparations[9]. While not a focus of the clinical literature, these advances are happening in pharmaceutical chemistry domains and are crucial for reproducible research. For instance, AI models can correlate certain chemical fingerprint patterns with higher clinical efficacy batches, thus guiding quality control towards aspects that matter therapeutically.

Overall, AI contributions to Ayurvedic drug discovery have been highly encouraging. They not only accelerate finding new uses for herbs (or confirming classical uses with scientific rationale) but also lend modern credibility to

Ayurvedic pharmacopeia by explaining modes of action. A real-world impact of this work is seen in areas like COVID-19 management: during the pandemic, some Ayurvedic formulations were investigated (like *Ashwagandha* for immunity). Data-driven selection of such candidates, guided by network models and prior knowledge, helped prioritize which formulations to test clinically when time was limited. Many challenges remain, such as the need for more comprehensive integration of phytochemical databases with Ayurvedic knowledge bases, and ensuring AI predictions are experimentally verified. But the trend suggests that Ayurveda could become a rich source of novel therapeutics for global problems, aided by AI to navigate its complexity. Additionally, by predicting safety issues early (herb toxicology, interactions), AI can help ensure that new Ayurvedic-inspired drugs meet modern regulatory standards. In the coming years, we expect to see more AI-identified Ayurvedic leads entering clinical trials, exemplifying a successful integration of traditional medicine and cutting-edge technology.

5. Panchakarma Protocols and Therapeutic Procedures

Panchakarma refers to the five major detoxification and purification therapies in Ayurveda (Vamana, Virechana, Basti, Nasya, Raktamokshana) which are highly individualized and administered in various sequences depending on patient condition. Optimization of Panchakarma - finding the ideal type, intensity, and sequence of therapies for each patient - is an area that has seen limited formal research, and accordingly, our review did not find any published studies (2020-2025) that directly use AI for Panchakarma protocol optimization. This appears to be a gap in the current literature.

However, conceptually, there is significant scope for AI to contribute in this domain, and some authors have discussed it in review articles or commentary. For instance, a narrative review by Kulkarni *et al.* (2023) on future Ayurveda trends posits that AI could analyze large patient datasets to discern which Panchakarma treatments yield the best outcomes for specific profiles of patients [17]. By mining electronic health records of Ayurveda hospitals (where Panchakarma details and outcomes are recorded), AI might identify patterns - e.g., that patients of a certain Prakriti with a certain disease respond better to a shorter course of Basti (medicated enema therapy) versus a longer one, or that the sequence *Virechana* then *Basti* leads to faster recovery in rheumatoid arthritis as opposed to the reverse order. Such insights could help in developing evidence-based guidelines, complementing classical textual guidance with outcome-driven data.

Another potential application is using predictive models to determine a patient's readiness and tolerance for Panchakarma. These therapies often have strong effects; knowing who might experience adverse reactions (like vasovagal episodes during Vamana induction of emesis, etc.) would be valuable. AI models considering patient vital statistics, lab tests, and prior responses could potentially forecast tolerance levels. While no formal study has been published, practitioners in integrative centers have started maintaining databases of Panchakarma results, which could feed into future AI analyses.

In the absence of concrete studies in our timeframe, we emphasize Panchakarma and related therapeutic optimizations as a *future scope*. The lack of current research might be due to the complexity of quantifying Panchakarma outcomes and the highly individualized nature limiting standard data collection. As Ayurveda centers increasingly adopt digital record-keeping (encouraged by initiatives like the AYUSH Grid in India), it is plausible that sufficient data will become available for AI analysis in the near future. For example, if thousands of patient records with detailed Panchakarma regimens and follow-up results are pooled, clustering algorithms might categorize responders vs. non-responders and highlight regimen differences.

In summary, while no direct AI implementations in Panchakarma were found in the literature through 2025, the consensus in expert discussions is that this is a fertile ground for research. It represents an opportunity where AI could help systematize one of the most complex interventions in Ayurveda, making it safer and more effective. We recommend that future systematic reviews revisit this topic as data-driven studies begin to emerge.

6. Remote Monitoring, Tele-Ayurveda, and Digital Health Platforms

The advent of telemedicine and digital health has expanded Ayurveda's reach, especially during the COVID-19 pandemic when remote consultations became a necessity. AI technologies play a role in enhancing these digital Ayurveda platforms in several ways:

- **Telemedicine and AI Triage:** Ayurvedic teleconsultation platforms have started incorporating AI-based triage systems. For instance, some tele-ayurveda apps include a preliminary questionnaire (symptom checker) that an AI processes to categorize the urgency or suggest possible Dosha disturbances before the patient even speaks to the doctor[18]. This can help prioritize patients who need immediate attention and provide the practitioner with a summarized analysis. One pilot study reported that an AI chatbot, trained on an Ayurvedic knowledge base, could correctly identify the probable category of ailment (e.g., respiratory vs. gastrointestinal and the likely dominant Dosha involved) in about 75% of cases compared to physician assessment[18]. Such chatbots also educate patients by answering common questions (e.g., diet tips for their Prakriti), functioning as an assistant in telehealth scenarios.
- **Remote Patient Monitoring:** We discussed earlier the example of IoT-based Nadi monitoring by Dubey *et al.* (2022) [6]. Extending that concept, remote monitoring devices can track various health parameters of Ayurvedic significance - for example, sleep patterns, physical activity, or even voice tone - and use AI to detect changes that may herald imbalance. Researchers have developed wearable sensors that could continuously gauge stress levels (via heart rate variability) and alert the user to perform calming Ayurvedic practices or take herbs if the AI detects a Vata aggravation trend. While these specific applications are still in development, they have been conceptually outlined in integrative health tech forums. A government-sponsored project in India (through the CCRAS) has also been exploring a "personalized Ayurvedic health tracker" which would use AI to integrate data from fitness bands with Ayurvedic questionnaires, giving users daily tips (though results are not yet published).

- **Digital Therapeutics and Personalized Feedback:** Some modern Ayurveda startups are delivering personalized wellness regimens through AI-driven platforms. For instance, an app might use AI to analyze a user's dietary logs, exercise, and stress levels (collected through phone sensors or manual input) and then provide tailored Ayurvedic dietary advice or yoga routines. These recommendations are often drawn from classical texts but prioritized by AI based on the user's specific data. A study in 2021 on a digital lifestyle intervention for diabetes combined an AI algorithm with Ayurvedic diet rules to coach patients. Over 3 months, the intervention group saw a greater reduction in fasting blood glucose compared to controls, demonstrating that such personalized digital coaching - essentially AI delivering Ayurvedic guidance - can be effective [19].
- **Integration with Mainstream Digital Health:** There are instances of AI being used to integrate Ayurvedic patient data with conventional electronic health records (EHRs). For example, an integrative medicine center in Kerala reported using a system where an AI maps patients' Ayurvedic diagnoses to ICD-10 codes (the international classification of diseases) for hospital records, and conversely, flags patients in the EHR who might benefit from Ayurveda consults based on patterns in their data [11]. Such bridging systems use NLP to interpret doctor's notes (identifying phrases like "joint pains recurring with weather changes") and suggest an Ayurveda referral for possible *Ama Vata* management in this case. This kind of integration, still experimental, is aimed at a future where AI helps create a seamless interface between Ayurvedic practitioners and other healthcare providers, improving patient outcomes through collaborative care.

During the COVID-19 pandemic, telemedicine in Ayurveda scaled up dramatically. Government AYUSH ministries launched helplines and tele-consult services, and initial analyses indicated high patient satisfaction and safety[9]. AI can further augment this by tracking population health trends. For example, AI analysis of teleconsultation data in 2020-21 revealed clusters of symptoms that responded well to certain Ayurvedic interventions, information that was fed back to refine treatment protocols [9].

In conclusion, AI in tele-ayurveda and digital health is helping in making Ayurvedic advice more accessible, personalized, and integrated. These technologies break geographic barriers, enabling patients worldwide to receive personalized Ayurvedic guidance through smart apps and wearables. The challenge lies in maintaining the personal touch and connection inherent to Ayurveda - AI must be designed to complement, not replace, the human aspect of healing. The reviewed trends suggest that when used judiciously (for triage, monitoring, reminders, education), AI can significantly enhance preventive care and chronic disease management via Ayurveda. It empowers patients with tools to manage their health in alignment with Ayurvedic principles on a daily basis, potentially increasing adherence to healthy routines (Dinacharya) and thus improving long-term outcomes. Future developments may see certified "digital therapeutics" incorporating Ayurvedic diet/yoga regimens prescribed by AI under practitioner supervision, expanding the reach of Ayurveda in public health.

7. Integration with Modern Medical Systems and Ayurgenomics

One of the forward-looking areas of research is *Ayurgenomics* - the integration of Ayurvedic concepts of personalized medicine with genomics and molecular biology. AI serves as a crucial facilitator in analyzing and finding connections in the complex data that arises from such integration:

- **Correlating Prakriti with Genomics:** Pioneering studies in earlier years (2015-2019) had shown that individuals of different Prakriti types have distinct profiles in certain gene expressions and biochemical markers. Recent work continues to build on this. For instance, Prasher *et al.* (2022) reported that transcriptomic analysis found significant differences in immune-related gene expression among the three main Dosha-based Prakriti groups [10]. Vata-predominant individuals showed upregulation of genes related to neural and synaptic functions, Pitta types showed differences in metabolic and inflammatory pathways, and Kapha types had distinct profiles in genes related to anabolic processes and coagulation [10]. AI comes into play by using clustering algorithms to see if genomic data can *unsupervisedly* cluster individuals in the same way Ayurveda would - interestingly, in one study, an unsupervised machine learning on gene expression data segregated subjects into clusters that closely matched their Prakriti classifications determined by vaidya assessment [11]. This lends scientific support to the Ayurvedic notion that Prakriti has a genetic basis, and AI was instrumental in uncovering that pattern from high-dimensional genomic data.
- **Predictive Models for Disease Susceptibility:** Ayurgenomics aims to predict health risks by combining Prakriti information with genetic predispositions. AI-based predictive models are being developed to this end. For example, a 2021 study looked at a gene (KCNJ11) involved in diabetes and found that certain polymorphisms correlated with Prakriti types; using machine learning, they could predict which Prakriti might be more susceptible to type 2 diabetes if carrying specific gene variants [20]. This kind of model could eventually lead to more personalized preventive strategies: an individual with a Kapha Prakriti (higher baseline risk for metabolic disorders in Ayurveda) *and* high-risk alleles in a metabolism gene could be flagged early for aggressive lifestyle intervention. AI is needed to handle the complexity of these gene-constitution interactions and to validate them on large datasets.
- **Multi-omics and Systems Biology:** Integration isn't limited to genomics. Some researchers are using AI to relate Ayurvedic types or diagnoses with microbiome profiles, metabolomics, and other *omics data. For instance, one study (Sharma *et al.*, 2023, in progress) uses deep learning to predict a person's Prakriti from their gut microbiome composition, under the hypothesis that Dosha balance influences or is reflected in gut flora. Early indications are that certain microbial genera are more abundant in, say, Pitta individuals vs. Kapha, and AI models can classify individuals above random

chance based on microbiome data. While very exploratory, this points to a future where AI helps validate Ayurveda's systemic effects by linking them to measurable biological networks.

- **Bridging Clinical Practices:** AI also helps practical integration in healthcare settings. Some hospitals use AI analytics on integrated datasets (combining Ayurvedic treatments and biomedical outcomes) to convince modern clinicians of Ayurveda's value. For example, an AI analysis of rheumatoid arthritis patients who received both methotrexate (a conventional drug) and Ayurvedic Panchakarma showed better joint function scores than those on methotrexate alone, which has spurred integrative treatment protocols [15]. By rigorously analyzing such data, AI provides evidence to inform combined Ayurveda-Western treatment guidelines.
- **Policy and Global Initiatives:** On a broader note, global organizations like WHO have recognized the role of AI in advancing traditional medicine. In 2023, the WHO, in partnership with ITU and India's Ministry of AYUSH, emphasized developing AI benchmarks for traditional medicine as part of the "Global Initiative on AI for Health" [1]. This has led to working groups that standardize data and outcome measures so that AI algorithms can be trained on multinational traditional medicine data. The involvement of AI in these initiatives underlines that integration of Ayurveda with modern health systems is on the international agenda, and data-driven approaches are key.

In summary, integration and Ayurgenomics represent the cutting-edge convergence of ancient and modern science. AI's ability to parse big data - whether genetic sequences or electronic health records - allows us to test Ayurvedic concepts under the lens of modern biology. The initial findings are validating: they show that Ayurvedic classifications often have analogues in objective biological variation. Going forward, this can revolutionize personalized medicine. For example, if an AI algorithm can use a person's genome, microbiome, and Prakriti to precisely tailor prevention strategies, it would fulfill the vision of *P4 medicine* (predictive, preventive, personalized, participatory) in a way that respects both Ayurvedic and modern perspectives.

That said, these efforts are still emerging and must be approached carefully. The risk of reductionism (forcing Ayurvedic concepts to fit genetic data) is there - Ayurveda's strength is in its holistic view, and not every aspect will map one-to-one with genes. Researchers caution against "genomic determinism" of Prakriti; rather, it's the complex gene-environment interplay (including epigenetics, which some are investigating in Ayurgenomics) that AI must unravel [10]. Interdisciplinary collaboration is essential: Ayurvedic experts ensure meaningful interpretations, while data scientists ensure robust analytics. With AI as the connecting tool, the future might see an enriched Ayurveda that can communicate in the language of modern science without losing its essence, ultimately benefiting patients through more validated and integrative care options.

Summary of Evidence Quality and Limitations

The studies reviewed vary in design and rigor. Many are pilot studies or proof-of-concept implementations. Common limitations include small sample sizes (especially in clinical or human subject studies), which raise concerns about over fitting of AI models and limited generalizability. Few studies employed external validation or independent test sets beyond internal cross-validation. Only a handful were prospective clinical studies; most were retrospective analyses or simulations. This means that while results are promising (high accuracies, etc.), they need to be confirmed in real-world prospective settings.

Another limitation is heterogeneity of outcomes - each study often defines its own metrics (one uses accuracy for Prakriti classification, another uses F1-score for a herbal prediction, etc.), making cross-comparison difficult. There is also an element of publication bias: successful applications get reported, whereas negative or null findings (which are equally instructive) might not be published as readily.

On the positive side, the interdisciplinary nature of these studies is a strength - almost all involved both technologists and Ayurveda practitioners, lending credibility and practical relevance to the AI models. The emerging trend of benchmarking (like using systematic review data or competitions for best model on a given Ayurveda dataset) will likely improve research quality.

In the Discussion that follows, we delve deeper into the implications of these findings, compare them with prior work (pre-2020 where relevant), and outline recommendations for future research and practice, taking into account the limitations mentioned here.

Discussion

This systematic review reveals that the integration of Artificial Intelligence into Ayurveda, which was speculative a decade ago, has started to yield tangible tools and insights in the period from 2020 onward. The findings across various domains demonstrate a clear trajectory: AI can *complement and strengthen* Ayurvedic practice, research, and education, but realizing its full potential requires navigating challenges unique to this traditional system.

Advancements and Comparison with Previous Literature

Compared to the state of the field pre-2020, recent years have seen more sophisticated AI applications. Prior to 2020, most works were limited to conceptual frameworks or very small expert systems. Now we have machine learning models trained on hundreds or thousands of data points, approaching performance levels that make them clinically useful (e.g., >90% accuracy in Prakriti classification) [3]. In earlier literature, Patwardhan and colleagues (circa 2012) had hypothesized that Prakriti correlates with genomic and biochemical parameters, but could only manually analyze small datasets. The current review shows that AI has been pivotal in confirming some of those hypotheses on a larger scale[10]. In pulse diagnosis too, devices like Nadi Tarangini existed for over a decade, but it's the recent AI-driven analyses that have enabled disease correlations to be uncovered [5]. This underscores that many earlier efforts laid the groundwork in data collection and digitization, which AI is now able to capitalize on.

It's also instructive to compare with parallel fields like Traditional Chinese Medicine (TCM). AI in TCM (for syndrome differentiation, tongue diagnosis, herb discovery) is slightly ahead, with numerous publications and even AI-driven diagnostic machines in hospitals. Ayurveda is catching up: our review finds similar areas being tackled (tongue, pulse, herbal networks) albeit in an earlier phase. A 2024 bibliometric review by Lim *et al.* showed exponential growth of ML research in TCM, and we see a comparable trend starting for Ayurveda[1]. This cross-comparison suggests that successes in one traditional system can often be translated to another with cultural adaptation - indeed, many AI approaches (like CNNs for tongue images) can be repurposed for Ayurveda. This cross-learning is happening; for example, Chinese researchers identified antibacterial herbs via network analysis, and Indian researchers applied that concept to Ayurvedic formulations with great success[8].

Key Benefits of AI Integration

The strengths highlighted by this review align well with Ayurveda's needs in the modern context. AI brings objectivity and consistency to Ayurvedic diagnostics - an area often criticized for inter-practitioner variability. When an ML model provides the same Prakriti assessment regardless of who runs it, it addresses a long-standing concern and could improve acceptance of Ayurveda in broader healthcare by ensuring reproducibility [2]. Similarly, AI's data crunching ability allows validation of Ayurvedic knowledge using large datasets, which can help in *evidence-based Ayurveda*. For example, by analyzing outcomes from thousands of patients, AI might validate that a classical formula for arthritis indeed has a 80% success rate in improving symptoms, and even identify which subset of patients benefit most. This kind of insight strengthens clinical decision-making and patient confidence.

Another benefit is personalization at scale. Ayurveda is inherently personalized, but scaling that to large populations was a challenge (it relies on expert human assessment which is time-intensive). AI can act as a force multiplier - simple AI-driven mobile apps can give millions of users personalized diet/exercise suggestions based on their Prakriti and daily health inputs, something not feasible through practitioners alone. This supports the preventive aspect of Ayurveda on a public health scale, potentially reducing disease burden by keeping individuals in balance.

AI also enhances integrative medicine. By providing a common data-driven language, it can relate Ayurvedic concepts to biomedical concepts, facilitating dialogue between Ayurvedic and allopathic practitioners. For instance, if an AI can show that "Pitta Prakriti with high Ama" correlates with a specific inflammatory marker elevation, it bridges understanding and opens avenues for integrative management (e.g., an allopathic doctor might be more inclined to refer a patient for Ayurveda detox once they see the correlation in familiar biomedical terms). Such integration is exemplified by the GDM risk model that combined biomedical and Ayurvedic factors [7] - it showed better predictive power than using either modality alone, which is a strong argument for integrated approaches.

Challenges and Limitations

Despite these benefits, the review highlights several challenges:

1. **Data Limitations:** High-quality, large datasets remain scarce in Ayurveda. Unlike conventional medicine, where multi-center trials produce big datasets, Ayurvedic interventions often vary case by case, and documentation isn't standardized. Many AI models reviewed had to rely on data from single centers or even single experts, which may encode subjective biases. This raises concerns about the AI's generalizability. For example, a Prakriti classifier trained on patients from North India might not perform as well in South India if subtle differences in interpretation exist. Efforts like the development of common data standards (perhaps an Ayurveda extension to electronic health records) and data sharing between institutions will be critical. The review by Nesari (2023) noted initiatives like DHARA (Digital Helpline for Ayurveda Research Articles) and Ayush Research Portal that compile research; building on these, creating anonymized data repositories for AI research would help [1].
2. **Epistemological Alignment:** Ayurveda's knowledge system is qualitative and holistic, whereas AI (especially statistical learning) can be reductionist. Ensuring AI models truly capture Ayurvedic constructs and not some proxy is non-trivial. For instance, if an AI Prakriti model just ends up correlating Prakriti with body-mass index and calling everyone with high BMI "Kapha" - that might statistically fit a portion of data but misses the deeper concept and could misclassify lean Kapha individuals. We have to guard against AI oversimplifying Ayurveda. This calls for close involvement of Ayurvedic experts at all stages: from feature selection (deciding which variables represent a Dosha) to validation (does the model's output make sense clinically?). It also suggests a need for developing Ayurveda-specific AI methodologies - perhaps customized algorithms that can handle non-linear combinatorial logic akin to Ayurvedic reasoning (some researchers have mentioned employing *fuzzy logic* to model Dosha states, which is interesting because Dosha imbalances are not binary and fuzzy logic allows partial truths).
3. **Validation and Regulation:** None of the AI systems discussed are yet widely deployed in clinical practice. Before that can happen, robust validation in prospective cohorts and ideally randomized trials is needed. For example, an AI recommendation system for diet should be tested to see if patients following its advice do better than those with standard advice. Additionally, who will regulate AI tools in Ayurveda? Regulatory bodies (like FDA or India's MoHFW) will need to set guidelines for approving such tools - and they'll need evaluative standards. Possibly, demonstrating non-inferiority to an Ayurvedic expert's decision might be a benchmark. Our review found very few studies tackling this head-on; most are technology-centric. So there is a gap in clinical evaluation, which needs to be addressed to translate these innovations into practice.
4. **Ethical and Privacy Issues:** As with any AI in health, privacy is a concern, especially since Ayurveda might collect non-standard personal data (like detailed lifestyle or mental state information). Ensuring secure handling of such data and obtaining proper consent is paramount. Moreover, ethical AI use means being transparent about the role of AI - patients and practitioners should know it's a tool providing suggestions, not an omniscient authority. The WHO's 2021 guidance on AI ethics for health is very relevant; it emphasizes human oversight, data governance, and algorithmic fairness [12]. For Ayurveda, fairness includes being mindful of diversity - AI models should be

trained on data that represent various populations (different regions, genders, ages) so they don't become biased toward one group's Ayurvedic characteristics.

5. **Acceptance and Training:** The uptake of AI tools by Ayurvedic practitioners depends on trust and usability. Some senior practitioners may be resistant, feeling that AI cannot grasp the "art" of Ayurveda. It will require clear evidence of benefit and extensive training to ensure these tools are used correctly. On the flip side, the new generation of practitioners might readily embrace AI, given adequate exposure in the curriculum. There's already a push to include basic informatics in Ayurveda education. A study on Ayurveda faculty showed moderate awareness of AI; efforts like seminars and pilot projects at institutes (e.g., an ongoing project at AIIMS and AIIA in India collaborating on AI in Ayurveda) are bridging this gap[9].

Strengths and Limitations of this Review
By focusing strictly on 2020-2025 and high-index journals, we aimed to capture the most current and credible information. A strength is the interdisciplinary lens we applied, evaluating technical performance as well as clinical relevance. However, this review also has limitations: the field is evolving so fast that new studies may have emerged during the review process that we could not include. Also, by excluding non-English works, we might have missed some developments (for example, some work in Ayurveda is published in Hindi or other regional languages, as well as relevant work in Chinese on TCM that could inspire Ayurveda applications). Additionally, due to space and scope, we summarized broad trends; each subfield (like Ayurgenomics or pulse diagnosis) merits a dedicated deep-dive review on its own for detailed technical critique.

Implications for Practice
In practical terms, what can an Ayurvedic practitioner or researcher take away from this? Firstly, a number of AI-based tools are likely to become available in the near future - from diagnostic apps to decision support systems - and practitioners should stay informed and engaged with these developments. They should consider participating in validation studies or even contributing data, as collectively building robust AI will require the community's involvement. Secondly, the incorporation of AI does not diminish the role of the Ayurvedic physician; if anything, it may automate routine aspects and free up the practitioner to focus on empathy, counseling, and deeper analysis that a machine cannot handle. In busy clinics, a quick AI-generated report (e.g., of a patient's Dosha tendencies or likely diagnosis) can streamline the visit, but the practitioner's judgment remains key in final decisions. Patients too may start using AI-guided wellness apps - practitioners should be prepared to guide patients in using them correctly and in interpreting their suggestions in proper context.

Future Research Directions
Building on the gaps identified, future research should aim to:

- Conduct large-scale, multi-center studies to validate promising AI tools (for example, test a Prakriti classifier across different demographics and see if health outcomes correlate with its classification better than with self-reported Prakriti).
- Explore AI in clinical trial design for Ayurveda - using AI to identify which patients are likely responders to a treatment, thus enabling targeted trial recruitment and personalized medicine research.
- Develop AI models for areas not yet studied, notably Panchakarma as discussed, but also others like Rasayana (rejuvenation therapy) scheduling, mental health in Ayurveda (perhaps AI could help quantify and track improvements in *Sattva* quality or stress as per Ayurvedic psychology), etc.
- Invest in creating shared Ayurveda data repositories with patient data (properly anonymized) available for research, under appropriate ethical frameworks. If various Ayurvedic colleges and hospitals contribute to a central database, AI development would accelerate.
- **Hybrid modeling:** combining knowledge-based and data-driven approaches. Pure machine learning might miss out on rich expert knowledge, while pure rule-based systems lack flexibility. A hybrid AI that encodes core Ayurvedic principles as a scaffold and learns nuances from data could be a powerful approach. Some preliminary work in this direction exists, but more is needed.
- **Education and Skill development:** Research on how to train Ayurvedic professionals in AI literacy is also important - ensuring that future generations can critically use and even develop AI solutions themselves.

In conclusion, the integration of AI in Ayurveda is an evolving paradigm shift. Our review indicates substantial positive strides and a foundation on which more rigorous, larger efforts can be built. The next decade will likely see AI move from the periphery (in labs and prototypes) to a more central role in mainstream Ayurvedic practice and research, much like it is doing in conventional medicine. The Ayurvedic community's proactive and thoughtful engagement with this technology will determine how beneficial and aligned with Ayurvedic values these tools ultimately become.

Limitations of the Current Evidence
While the results of this review are encouraging, it is important to acknowledge the limitations inherent in the current body of evidence:

- **Early Stage Research:** Much of the work cited is at a preliminary stage - many studies are pilot projects, proof-of-concept demonstrations, or feasibility studies. They provide initial evidence of AI's potential but are not definitive. Large confirmatory studies or randomized trials are generally lacking at present.
- **Sample Size and Diversity:** Several studies involved relatively small samples or narrow population groups. For example, an AI model for Prakriti might be trained on a few hundred individuals predominantly from one region or ethnic background[3]. Ayurveda is practiced globally and patient characteristics vary widely; models built on limited data may not perform well universally. This raises concerns about the external validity of some findings. Future studies need more diverse and larger datasets to ensure robustness.
- **Study Design Constraints:** Few studies were longitudinal or had control groups. As a result, for

intervention-related AI (like decision support for treatment), we have limited evidence on actual patient outcomes. We might know an AI can *make a recommendation*, but not whether following that recommendation yields better health outcomes versus standard care. Also, many studies were retrospective, which can introduce bias in how data was collected or labeled (for instance, using medical records where data quality may be inconsistent).

- **Reporting and Publication Bias:** It's possible that not all attempts to use AI in Ayurveda have been successful, but unsuccessful or null results might not be published. This could skew the literature to appear more optimistic than reality. The review tries to balance this by critical appraisal, but we can only analyze what is reported in literature. Also, interdisciplinary work like this sometimes appears in non-indexed sources or conference proceedings that can be harder to find systematically.
- **Measurement of Ayurvedic Outcomes:** A limitation specific to this field is the difficulty of quantitatively measuring some Ayurvedic outcomes. How do we definitively measure "improvement in Prakriti balance" or "reduction in Ama"? Some studies used proxy measures (e.g., symptom scores or lab values), but there is a risk that these proxies don't capture the full Ayurvedic concept. This can make evaluation of AI's impact challenging. There's an ongoing need to develop standardized outcome measures for Ayurvedic interventions that can be widely accepted, which will aid future research quality.
- **AI Model Transparency:** Many AI methods, especially complex ones like deep learning, are "black boxes." In healthcare this is a known concern - models might make accurate predictions but without explaining the rationale. In an Ayurvedic context, this opaqueness could be at odds with the traditionally logic-driven approach of choosing treatments. A patient or practitioner might want to know *why* the AI suggested a certain herb. Current evidence seldom addresses this interpretability. Future work should incorporate explainable AI techniques, so that models provide reasoning in Ayurvedic terms (e.g., "suggesting herb X because it reduces Pitta and patient shows signs of Pitta aggravation").
- **Real-world Implementation Challenges:** None of the studies fully addressed the practical challenges of implementing these AI solutions in real clinical settings at scale. Issues like integration with clinic workflow, training staff, patient acceptance, cost-benefit analysis, etc., were generally outside the scope of these research papers. Therefore, even if the evidence suggests a tool *could* work, we have limited information on how it *would* work in day-to-day practice. This is not a fault of the studies per se (which are understandably focused on technical feasibility or initial efficacy), but it means there is a gap between research findings and readiness for healthcare deployment.

By recognizing these limitations, we can better contextualize the conclusions of this review. The evidence base, though rapidly growing, is still maturing. Stakeholders should view current AI tools for Ayurveda as experimental adjuncts rather than standalone solutions. The promise is real, but caution and rigorous validation are needed in translating these innovations into practice. Encouragingly, awareness of these gaps is rising within the community - we see calls for more systematic data collection, better study designs, and collaborative research, which if acted upon will strengthen the evidence in coming years.

In summary, the current evidence is like a prototype: it shows the outline of what's possible when AI meets Ayurveda. It remains to refine that prototype through larger, well-designed studies, to ensure that when scaled up, these AI applications are safe, effective, and genuinely beneficial to patients. The limitations noted here should guide researchers to design the next wave of studies that address these issues, thereby elevating the quality of evidence and confidence in AI-integrated Ayurvedic care.

Future Scope and Recommendations

Building on the findings and acknowledging the current limitations, this section outlines the future scope of AI in Ayurveda and provides recommendations for research, practice, and policy:

1. Large-Scale Collaborative Research: There is a clear need for multi-center, large-scale studies to validate AI tools in Ayurveda. We recommend establishing collaborative networks among Ayurvedic institutions to pool data. For example, a consortium could undertake a prospective study where multiple clinics use a standardized AI-based Prakriti assessment app, and outcomes for patients (in terms of treatment response or patient satisfaction) are tracked over time. Such collaboration would increase sample size and diversity, improving the generalizability of AI models. Moreover, multi-center trials of AI-guided interventions (e.g., AI-recommended diet plans vs. standard advice in managing a chronic disease) could rigorously evaluate clinical impact. Funding agencies and AYUSH ministry bodies should prioritize grants for such collaborative projects.

2. Standardization of Data and Reporting: To truly harness AI, Ayurveda needs more standardized data capture. We suggest developing a common minimum dataset for Ayurvedic clinical encounters that can be used in electronic health records (EHRs). This should include fields for Prakriti determination (perhaps a standardized questionnaire), symptom scores for common complaints, treatment details (down to the formulation and dose), and outcome follow-ups. Adoption of such standards (possibly as an "Ayurveda module" in existing hospital EHR systems) will make it easier to aggregate and analyze data across different settings. Additionally, reporting guidelines for studies on "AI in Ayurveda" should be formulated (akin to CONSORT for trials, we might have specific considerations to report Dosha-related details, etc.), which will improve transparency and reproducibility in publications.

3. Development of Explainable AI for Ayurveda: Future AI systems should strive to be not only accurate but also interpretable in Ayurvedic terms. Research in *Explainable AI (XAI)* should be applied to this field. For instance, if a neural network predicts a diagnosis, methods like SHAP (SHapley Additive exPlanations) could be used to highlight which inputs (symptoms, signs) influenced that decision the most - often aligning with how a physician would explain their rationale. Efforts could also be made to encode

Ayurvedic knowledge into model architecture (e.g., a model might have intermediate nodes representing Dosha levels). By doing so, the AI's workings mirror Ayurvedic reasoning to a degree, making it easier for practitioners to trust and verify recommendations. We recommend an interdisciplinary approach where AI specialists work closely with Ayurvedic scholars to embed domain knowledge into algorithms.

4. Integration with Conventional Healthcare and Bridging Platforms: The future of Ayurveda, especially in urban and global contexts, is likely to be as part of an integrative healthcare system. AI can facilitate the integration by acting as a bridge. We foresee AI systems that can automatically translate Ayurvedic diagnostic findings into biomedical risk factors and vice versa (for example, an AI that reads a patient's medical history from a regular doctor and alerts the Ayurvedic physician about aspects relevant to Ayurvedic evaluation). Developing such integrative decision support systems is a worthy goal. For instance, an AI-based dashboard for a patient could show both Ayurvedic parameters (Dosha imbalance, Agni status) and biomedical parameters (lab results, imaging findings), highlighting connections (AI might note: "Patient's elevated liver enzymes correlate with signs of Pitta aggravation"). This holistic view could foster truly integrative case discussions. Collaboration with hospitals that offer both Ayurvedic and allopathic services would be an ideal testbed for such technologies.

5. Education and Capacity Building: We recommend updating Ayurvedic educational curricula to include basics of AI and data science. Just as medical schools now teach about health informatics, Ayurvedic colleges should introduce courses on biomedical statistics, AI fundamentals, and digital health. This will prepare new practitioners to comfortably use AI tools and even contribute to their development. Furthermore, workshops and continuing education programs can upskill current practitioners. Initiatives like hackathons or joint seminars between tech institutes and Ayurveda institutes could spark interest and innovation (for example, an annual "AI for Ayurveda" challenge where teams compete to develop the best model for a given problem). Building such capacity ensures that the technology remains under the guidance of Ayurvedic insight and isn't something imposed externally without full understanding.

6. Ethical Framework and Guidelines: It is prudent for regulatory bodies and professional councils (like the Central Council of Indian Medicine, CCIM) to start formulating guidelines on the ethical use of AI in Ayurvedic practice. These guidelines should address informed consent (patients should know when AI is aiding their care), data privacy (especially for apps collecting sensitive personal information), and accountability (the practitioner should ultimately be responsible for decisions, not deferring blindly to an AI). Additionally, as AI tools may be commercialized, guidelines about validation and certification will be needed. For example, a possible framework is to require that any AI-driven diagnostic tool for Ayurveda undergo an independent evaluation study and get approval from a body similar to how drugs or medical devices are approved. The guidelines might categorize AI tools (diagnostic aid, treatment recommendation, patient self-management tool, etc.) and stipulate the level of evidence required for each category. Starting to discuss and draft these frameworks now, in consultation with technologists, ethicists, and vaidyas, will ensure safe and effective integration as the tech becomes more widespread.

7. Expanding Research to Underexplored Domains: Our review identified underexplored areas like mental health (Manas prakriti, etc.), public health and epidemiology (could AI predict outbreak of certain seasonal disorders by analyzing climate and Dosha patterns?), and cross-practice outcomes (how AI might help in documenting outcomes of combining Ayurveda with Yoga, for example). These represent future scope. We recommend funding and encouraging pilot studies in these areas. For mental health: perhaps AI could analyze speech or text (NLP on what patients say) for signs of rajas/tamas disturbances. For community health: AI could look at environmental data and traditional calendar to foresee when disorders like cough/cold (Kapha disorders) might spike and help authorities issue preventive advisories (this aligns with the concept of Ritucharya-seasonal regimen). Such innovative applications should be pursued.

8. Global Collaboration and Knowledge Sharing: Ayurveda is practiced in many countries now, and AI is a field without borders. International collaboration can accelerate progress. For instance, an AI model trained on Indian data might be tested on European patients of Ayurveda to see if concepts transfer; if discrepancies are found, that offers insight into how Ayurveda might manifest differently in different genetic pools or lifestyles. Sharing de-identified data globally could enrich AI models. We encourage international conferences and working groups on "AI in Traditional Medicine" where Ayurveda, TCM, Unani, etc., experts compare notes. The WHO's Global Centre for Traditional Medicine (just established in 2022 in India) could be a platform to foster such collaborations, ensuring that best practices and findings are disseminated widely.

In conclusion of Future Scope: The next steps should be both ambitious and cautious - ambitious in leveraging AI's full potential to revitalize and validate Ayurveda, and cautious in maintaining the integrity of Ayurvedic knowledge and prioritizing patient welfare. If the recommendations above are pursued, we anticipate in the next 5-10 years an Ayurveda ecosystem where routine use of AI is standard: practitioners use tablets or devices that give them Dosha analyses and suggest treatments (like a smart *Nighantu* or formulary at their fingertips), patients engage with personalized wellness apps that keep them aligned with Ayurvedic routines, and researchers rapidly crunch clinical data to continuously update and refine protocols. It's a vision of Ayurveda 2.0 - deeply rooted in tradition, yet enhanced by technology - and it stands to benefit individual patients and global healthcare alike by offering a more personalized, preventive, and holistic care model. Achieving it will require sustained effort, cross-disciplinary respect, and adherence to both scientific and Ayurvedic principles.

Conclusion

Artificial Intelligence is ushering in a new era for Ayurveda, transforming aspects of this age-old medical system in ways that can enhance its precision, accessibility, and integration with mainstream healthcare. This systematic review of studies from 2020 onwards demonstrates that AI applications in Ayurveda are no longer just theoretical proposals but practical realities showing notable success: machine learning models can accurately determine an individual's Prakriti, sensor-based systems can objectify and analyze the Ayurvedic pulse, and computational algorithms can mine classical texts or biochemical data to unearth promising Ayurvedic remedies. These innovations strongly indicate that the data-driven rigor of AI can complement the experiential wisdom of Ayurveda, creating tools that uphold the authenticity of Ayurvedic diagnostics and therapies while meeting modern benchmarks of evidence and consistency.

Key findings of the review highlight that AI-driven personalization is a game-changer. Ayurveda has always been personalized; now with AI, the tailoring of lifestyle advice or herbal prescriptions can be even more finely tuned, using insights from large datasets and patterns that no single practitioner could discern alone. Similarly, AI-based decision support can aid practitioners in diagnosing complex cases or considering integrative treatment options, thereby potentially improving patient outcomes and safety (for instance, by flagging possible herb-drug interactions or suggesting additional investigations in ambiguous cases). In the domain of drug discovery, AI has accelerated the identification of bioactive leads from Ayurvedic herbs, bridging traditional knowledge and modern pharmacology in a way that could yield new treatments for contemporary health challenges. Furthermore, AI-facilitated telemedicine and remote monitoring have extended the reach of Ayurveda, making personalized guidance available beyond the clinic and empowering patients in self-care aligned with Ayurvedic principles.

Despite these advancements, the review also underscores that we are at an early stage of fully realizing AI's benefits for Ayurveda. The current evidence, while promising, is largely composed of initial studies that must be expanded and validated. Ensuring that AI tools truly enhance Ayurvedic practice requires careful stewardship: integrating them in clinical workflows thoughtfully, training practitioners to use them effectively, and validating their recommendations against the touchstone of clinical outcomes and patient well-being. Importantly, AI should be viewed as an aid, not a replacement, to the Ayurvedic practitioner. The human element - the insight, intuition, and empathetic understanding of the Vaidya - remains irreplaceable. AI can crunch data and suggest patterns, but it cannot replicate the healer's wisdom in understanding a patient's unique context or the subtleties of the doctor-patient relationship that are so pivotal in Ayurveda's holistic approach.

Thus, the way forward is a synergistic one: by combining the "art and science" of Ayurveda with the computational power of AI, we can evolve an integrated practice that is both robustly evidence-informed and profoundly individualized. This will involve ongoing research (expanding sample sizes, exploring new domains like Panchakarma optimization), capacity building among Ayurvedic professionals in digital literacy, and open channels of collaboration between technologists and Ayurveda experts. If these are pursued, the next decade could witness Ayurveda emerging as a frontrunner in *personalized medicine on a global stage*, supported by AI-driven validation and innovation.

In conclusion, AI in Ayurveda is not about mechanizing an ancient art, but rather about illuminating and strengthening it. By harnessing AI, Ayurveda can demonstrate its principles in the language of modern science, increase its appeal and credibility among new generations, and most importantly, improve healthcare delivery by ensuring patients receive the right advice and treatment at the right time, tailored to their unique constitution and needs. This confluence of Brahma-vijnana (knowledge from the creator, i.e., ancient wisdom) and Yukti-vijnana (rational analysis, where AI now plays a role) is a compelling narrative of continuity and change. The marriage of AI and Ayurveda holds immense promise: preserving the holistic essence of Ayurveda while elevating it with 21st-century tools, for the betterment of individual and public health. It is a journey that has just begun, and the evidence so far suggests that with mindful advancement, it will greatly enrich the tradition and practice of Ayurveda in the years to come.

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