

## Review Article

# Integrating agent-based modelling with Ayurvedic principles a conceptual framework for systems health

Pramod Chandra Dwivedi<sup>1\*</sup>, Pulsi Pande<sup>2</sup>, Madan Mohan Sharma<sup>1</sup>, Amit Kumar<sup>1</sup>

<sup>1</sup>CCRAS-Regional Ayurved Research Institute, Gwalior, Madhya Pradesh, India

<sup>2</sup>Government Ayurved College, Rewa, Madhya Pradesh, India

**Received:** 22 January 2026

**Revised:** 22 May 2026

**Accepted:** 26 May 2026

### \*Correspondence:

Dr. Pramod Chandra Dwivedi,

E-mail: [dpramod825@gmail.com](mailto:dpramod825@gmail.com)

**Copyright:** © the author(s), publisher and licensee Medip Academy. This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

## ABSTRACT

The emergent nature of health and disease is due to the complexity of interactions between the biological system, behavioural system and the environmental system. In Ayurveda, the traditional Indian system of medicine, the human organism has traditionally been viewed as a living system of Dosha (functional principles), Dhatu (tissues), Agni (metabolic energy) as well as Shrotas (circulatory channels). These organizations constantly are at work with both internal and external variables in order to preserve harmony within the system. The current systems biology and computational science is also understanding health as an emergent phenomenon of complex adaptive systems. which gives a framework of enormous power to computational simulation. This review seeks to understand the conceptual and methodological combination of Ayurvedic principles with Agent-Based Modelling in order to develop a systems framework of organising, predicting and controlling the dynamics of health and disease. Narrative and conceptual review was done ensuring that classical Ayurvedic literature is analysed together with the modern systems biology, computational models, and ABM readings. Ayurvedic objects were equated to computational analogs: Dosha as control agents, Dhatu as a structural matter, Agni as the processors of metabolism, Ama as mala adjusting products and Shrotas as the communication channels. It has been used to develop a conceptual model of human physiology as a multi-agent system the interactions of individual agents governed by the Ayurvedic laws of balance and feedback regulation give rise to global health. Findings: The proposed schematic illustrates how ABM has the capability of simulating Ayurvedic processes (Prakriti (individual constitution), Samprapti (pathogenesis), and Chikitsa (therapeutic intervention)) using computational logic.

**Keywords:** Ayurveda, Agent-based modelling, Systems health, Dosha, Personalized medicine, Systems biology

## INTRODUCTION

Traditionally and modernly, health is considered as a dynamic, and not a fixed, relational position of existence. It represents the process of constant interaction and adjustment of an organism to the internal and external environment. The ancient Indian health system Ayurveda offers one of the most elaborate systems of health and is inherently systems based.<sup>1</sup> It talks of the human body as a self-governing, complex set of components that interact with and regulate each other including Dosha (functional

energies), Dhatu (tissues), Mala (wastes), Agni (metabolic fire), and Shrotas (circulatory and communication channels). Varya Sama Avastha among these elements brings about health whereas their disequilibrium (Vikriti) brings about disease.<sup>2</sup> The power of Ayurveda is that it has a strong appreciation of functional interdependence, adaptive feedback processes and constitutive particular (Prakriti). Every individual is perceived as a unique system having particular configurations of reacting to diet, surroundings, feelings, and stressors. Therefore, Ayurvedic diagnosis and

treatment are adaptive and personalized by nature, which the contemporary precision medicine and systems biology are currently working to achieve. The Ayurveda philosophy of health as a dynamism, and not the absence of disease, makes Ayurveda among the earliest type of systems medicine.<sup>3</sup>

Modern biomedical science, on the contrary, has traditionally conformed to a reductionist paradigm, that is, by isolating particular variables, determining causal mechanisms. Although it is very useful in drug discovery and in molecular understanding, this method has a tendency of failing to reflect emergent properties of complex biological systems, including resilience, flexibility and non-linear dynamics. To overcome these drawbacks, modern health sciences tend to resort to the systems based computational methods, and Agent-Based Modelling (ABM) has been truly rising into prominence.<sup>4</sup>

ABM is a bottom-up algorithm technology that theorizes the conduct of discrete units (agents) and their connections within a system. All agents act based on a rule system, and the result of the system level can be seen as a combination of these interactions at a micro-level. The features of ABM are unlike equation-based or statistical models: heterogeneity, feedbacks, and stochastic events can all be included in it, which are attributes of biological and social complexity. ABM has been used in health sciences to simulate disease spread, immune interactions, pharmacodynamics and behavioural health interventions.<sup>5</sup>

The theory of Ayurveda and ABM is conceptually impressive. Ability of Ayurveda to view health emergently by interactions of various physiological and environmental factors is exactly what ABM attempts to compute by network simulation.<sup>6</sup> Again, the same can be said about Agni, which is a metabolic engine that opens up change and Shrotas in which this change is carried throughout. Complex adaptive responses are a result of perturbations in these systems and are explored well using ABM simulations.<sup>7</sup>

Through incorporating the Ayurvedic ideas into ABM, we can come up with a quantitative systems framework that will connect the traditional world of holistic knowledge and modern science of computers. This method could be used to imagine that Samprapti (pathogenesis) is an ever-changing process, not the cause-effect plan. It empowers the modeling of the spread of imbalances within networks of physiological interactions and the ability to perceive, with great accuracy, individualized interventions to restore balance.<sup>8</sup> Furthermore, this type of integration would be in line with the modern trend towards the predicted, preventive, personalized and participatory (P4) medicine. The philosophical and clinical base is furnished by Ayurveda and the computational structure is furnished by ABM. The possible uses are enormous--between one approach to simulate personalized treatment results and community

wellness interventions and another of the epidemiological dynamics of an Ayurvedic population using the theory of Ayurvedic epidemiology.<sup>9</sup> Nonetheless, it is not that easy to integrate these paradigms. Conceptual clarity and interdisciplinary workforce to translate qualitative Ayurvedic variables, including Guna (qualities), Prakriti (constitution), and Vikriti (imbalance), to computational parameters is necessary. However, the possible benefits are high: ABM has a potential to become a digital Ayurveda laboratory, where researchers can test hypotheses, validate traditional formulations, and experiment on personalized treatment methods in silico before applying them in a real clinical setting.<sup>10</sup> This review therefore suggests an introductory level towards the merge of Agent-Based Modelling and Ayurvedic concepts in order to advance the perception of the systems well-being. It will attempt to establish the path to a new STP crossover science, Computational Ayurveda Systems Health that respects the wisdom of tradition, but uses the analysis power of modern science.

### ***Aims and objectives***

The objectives of this study are to conceptualize the integration of agent-based modelling with Ayurvedic principles, to identify Ayurvedic parameters that can be represented computationally as agents, to propose a systems-based framework for modelling health and disease dynamics, and to explore potential applications of agent-based modelling in Ayurvedic clinical research and personalized medicine.

## **METHODS**

### ***Literature review approach***

A literature review was carried out by examining the PubMed, Scopus, and AYUSH portal sources with the key words including Ayurveda systems biology, Agent-Based Modelling in healthcare, holistic medicine, and computational Ayurveda. Systems science, computational biology as well as Ayurvedic classical texts (Charaka Samhita, Sushruta Samhita, Ashtanga Hridaya) were subject to comparisons and syntheses.

### ***Conceptual mapping***

The mapping of Ayurvedic entities to computational elements was carried out as follows: Dosha were represented as regulatory agents influencing system stability, Dhātu as structural agents responsible for maintaining body integrity, Agni as a metabolic agent regulating transformation processes, Ama as a dysfunctional byproduct agent affecting system interactions, and Shrotas as pathways governing communication and flow within the system. Based on these mappings, simulation scenarios were suggested to demonstrate how the system perturbations (e.g. aggravation of Vata or dysfunction of Agni) result in emergent pathological patterns.

## **Conceptual framework**

### *System architecture*

Human organism is considered a multi-agent system with each agent (cell, tissue, organ) being subordinated to the global homeostatic rules, inherently, by Dosha balance. All of the agents of Dosha (Vata, Pitta, Kapha) possess behavioural rules that determine the strength of interaction, malleability and impact on local agents.<sup>12</sup>

### *Dynamic interactions*<sup>13</sup>

Vata governs movement and communication between agents within the system, facilitating dynamic interactions and information exchange. Pitta is responsible for transformation and metabolic signaling, regulating processes of conversion and energy utilization. Kapha ensures stability and structural cohesion, maintaining balance and integrity within the system. The interactions can be represented using feedback loop, adaptation thresholds and emergent dynamics similar to the cybernetics system.

### *Discovery of perturbations and an emergence of a disease*<sup>14</sup>

Disease dawns with surpassing of adaptive capacity by agent or category of agents- analogous with Dosha vitiation. ABM makes it possible to simulate these nonlinear transitions, in which minor change can develop into systemic imbalances.

### *Intervention modeling*

External agents that can be simulated to restore a balance in the system are Ayurvedic interventions (herbal formulations, Panchakarma, diet, and lifestyle). The interventions-agent behaviour feedback gives the ability to predict outcome pathways and design individualized therapies.<sup>15</sup>

## **DISCUSSION**

The combination of Agent-Based Modelling (ABM) and Ayurvedic construct is a new and interdisciplinary interjection between indigenous holistic knowledge and contemporary computational science. This conceptual synthesis does not only justify the systems-based Ayurveda knowledge of the human body; it also increases its prospective to be explored quantitatively and predictively.<sup>16</sup>

### ***Ayurveda and systems thinking: ayurveda and systems thinking natural parallels***

Ayurved did not lie outside of the systems sciences. It conceptualizes the human body as a dynamic, adaptive system that is involved in constant interaction with physiological, psychological and environmental variables.

One of these theories, the Tridosha, Vata, Pitta, and Kapha, summarizes regulatory processes, which are system controllers in cybernetics. Vata, Pitta and Kapha are the motion, transformation and metabolism and stability and structure respectively. The two of them ensure homeodynamic balance.<sup>17</sup>

In systems biology, one can say the same thing about the concepts of feedback regulation, self-organization, and emergent behaviour. Dosha can be modelled using ABM with it being represented by separate classes of agents having particular behavioural regulations affecting the system dynamics. In one instance, Pitta over stimulation may mimic hypermetabolic processes or inflammatory, whereas Kapha domination may reflect decreased flexibility or obstruction at the whole-body systems.<sup>18</sup>

The correspondence between Ayurveda and agent-based computational translation brings Ayurveda as a naturally compatible philosophy. This Modeling of the relationship between Dosha, Agni, Dhatu, Shrotas and environmental stimuli enables an individual to see the complex adaptive landscape of health as Ayurveda sees it.<sup>19</sup>

### ***ABM as the visualization of ayurvedic dynamics***

ABM is an excellent model in the art of studying emergent behaviour that occurs as a result of local interacting agents. As opposed to traditional deterministic models, the ABM addresses heterogeneity and stochasticity which are attributes highly relevant to Ayurvedic individuality (Prakriti).<sup>20</sup>

Every type of Prakriti (Vata, Pitta, Kapha or their combinations) may be represented as a starting condition set that specifies the agent properties including adaptability, speed of interaction and recovery capability. For example: Systems that are Vata-predominated tend to be highly variable and respond quickly to changes, but they may lack stability.<sup>20-22</sup> Kapha-dominant systems generally show lower adaptability, although they possess greater resilience and structural steadiness. Pitta-preeminent systems are often characterized by efficient transformation and effective change, but they may become excessively active or intense when exposed to stress. These simulations may be used to simulate variations of physiology and psychology of the real world, and are able to give visual understanding of balance (Vikriti) becoming disease (Vyadhi). Additionally, with ABM, it is possible to test interventions (e.g., Ahara (diet), Vihara (lifestyle), Aushadha (medicine)) as external regulatory inputs that put the system back in balance.<sup>23</sup> This type of model might develop our knowledge of the Ayurvedic pathophysiological concept of Samprapti, into a dynamic, emulable simulation. An example is the Ama (metabolic toxin) build-up and Shrotorodha (channel blockage) which can be modeled as agent-level feedback restrictions on system efficiency. This allows one to visualize disease

progression and therapeutic reversal processes in real time.<sup>24</sup>

### ***Ayurveda towards predictive and personalized ayurveda***

The best feature of Ayurveda is personalization. All the diagnoses and treatments plans take into consideration Prakriti, Vikriti, diet, lifestyle, climate and emotional issues. Precision health now allows modern medicine to work toward the same goal with the help of genomics, metabolomics, and analytics based on the AI. ABM provides a useful computational either side between these worlds.<sup>25</sup> The agent-based model (ABM) can function as a predictive engine by encoding Prakriti-specific parameters to automatically anticipate Ayurvedic responses to individual interventions.

For example, it can help in identifying individuals who are more vulnerable to Vataja or Pittaja conditions under environmental stress, simulate the systemic effects of herbal preparations such as Triphala or Ashwagandha on physiological balance, and optimize Panchakarma detoxification schedules based on the adaptive responses of different Prakriti profiles. In public health, agent-based simulations could model how population-level factors (dietary habits, seasonal variations, circadian rhythms) influence collective health trends through an Ayurvedic lens. This could guide preventive strategies in community wellness or epidemic preparedness based on Ayurvedic epidemiology (Janapadodhwamsa theory).<sup>26</sup>

### ***Translating qualitative ayurveda into quantitative ABM***

One of the major challenges in integrating ABM with Ayurveda is the translation of qualitative constructs into measurable computational variables. Concepts such as Guna (qualities), Virya (potency), or Vipaka (post-digestive effect) are inherently qualitative, context-dependent, and multidimensional.<sup>27</sup>

One of these solutions is the parameter mapping via multidisciplinary cooperation.<sup>28,29</sup>

*Physiological correlates Vata:* Vata might have physiological equivalents in neuronal signaling and bioelectrical communication, Pitta: Pitta neural signaling and bioelectrical communication might be equivalent to enzymatic and/or metabolic activity, Kapha: Kapha neuronal union There need to be an equivalent of kapha neural union to enzymatic and/or metabolic activity.

*System parameters:* it is possible that Agni correlates with metabolic rate or efficiency of conversion of energy into ATP molecules and accumulation of unprocessed metabolites or inflammatory mediators with Ama.

*Network topology:* Shrotas are equivalent to transport networks (vascular, lymphatic, neural), the performance of which can be measured as the communication bandwidth or flow rate.

Rule-based agent interactions are also definable using such mappings. Direct experimental/clinical correlations of these parameters (e.g. heart rate variability, cytokines levels, or genomic markers of Prakriti) can gradually increase model accuracy.

### ***Research and clinical implications***<sup>30</sup>

ABM use in Ayurvedic studies would transform several spheres:

*School preaching and pictorialism:* Simulation-based models might allow the visualization of Samprapti, Dosha, and treatment effects in the students and practitioners dynamically, and hence making traditional learning more instinctual and representationally consistent.

*Drug discovery:* The drug's effect relies on the inhibition of the networks activated by the initial stimuli, which leads to the production of dopamine<human>Drug.

*Discovery and pharmacodynamics:* ABM is able to recapitulate the multi-target response of Ayurvedic preparations, which represents the polyherbal synergy which is frequently overlooked in reductionist pharmacology.

*Clinical decision support:* Integrated models might be used as diagnostic or prognostic models, predicting the outcome of patients on the basis of Prakriti, lifestyle information, and concerned biometrics, which can help in precision therapeutics.

*Epidemiological modelling:* The concept of Ayurvedic epidemiology alongside ABM has the potential to model the effects of season and environment on the transmission of diseases, as far as approaches to Ritucharya and Deshachar adhere to.

### ***Problems and future projection***<sup>31,32</sup>

Although promising, there are still a number of methodological and philosophical issues:

*Information unavailability:* Ayurvedic models are constrained by unavailable official quantitative data of Ayurvedic information.

*Conceptual abstraction:* It is very easy to make complex Ayurvedic constructs conceptually simpler and intoxicate their philosophical meaning.

*Search across disciplines:* The need to develop an effective model requires the collaboration of Ayurvedic scholars, computational scientists, biostatisticians and clinicians.

*Validation models:* The models will have to be clinical or biomarker-correlated to validate the model.

*Ethical and epistemological fit:* It is very important to consider Ayurvedic ontology and to incorporate the contemporary approaches in order to avoid reductionism.

Future investigations should be made to design hybrid frameworks that the ABM would be used as a complement of systems biology and the AI-based predictive analytics. Machine learning could be useful to parameterize agent behaviour whereas ABM could simulate emergent phenomena. This synergy has the potential to result in digital twins of Ayurvedic patients-estimated models of the physiological and constitutional state of actual people to help them in the creation of a personalized intervention program.

### **Convergence to a unified science of systems health**

The Ayurveda and ABM synthesis are an example of the change in the overall treatment of the disease to optimization of the health system. It cuts across the realms of the various disciplines and opens up a new epistemology Ayurvedic Systems Health Science (ASHS) that perceives the human being as an intricate adaptive environment.

By enabling the computational representation of the Ayurvedic dynamics, researchers are able to investigate how self-regulation, adaptation, as well as resilience can be represented as a result of interaction of various forces. This paradigm fits well within the framework of global health in which one Health, planetary health, and a healthy health system have contributed to worldwide interest.<sup>33</sup>

Finally, the combination of ABM with Ayurveda can not only be able to modernize the traditional medicine, but also increase the scientific knowledge related to the concept of life as a self-organizing, intelligent, and adaptive system that exists under the universal laws of balance and transformation.<sup>34</sup>

### **CONCLUSION**

The meeting of Ayurvedic systems philosophy with Agent-Based Modelling (ABM) marks another important step in rethink of health and disease as a dynamic, emergent phenomenon, but no longer a static state. Thousands of years ago, Ayurveda has perceived human life as an ever-changing system and treated by physical, psychological, environment dependent factors. It focuses on homeodynamic balance of Dosha, Dhatu, Agni and Shrotas another idea that is close to contemporary systems biology and complexity science. ABM, however, offers a computational laboratory where one can model such complexity and compute and study it in a quantitative fashion.

It brings into being the heterogeneity, feedback mechanisms, and adaptive behaviour, qualities that are inherent in Ayurvedic philosophy. Simulation of dynamic

Samprapti (pathogenesis) processes, simulation of the effects of Ayurvedic agents of many Aha-Vihara-Aushadha, and investigation of the influence on individualized factors on health trajectories (such as Prakriti and Agni) are possible by modeling Ayurvedic entities as interacting agents. This is integration creating the frontier of computational Ayurveda or the science of simulating Ayurvedic systems using computational logic. In this context, Dosha can play a role of controlling the overall behaviour of the system, Agni can play a role of ruling the metabolism, and Shrotas can play a role of communication channels.

Their interactions are explainable using ABM so as to illustrate how balance or imbalance can be built using micro interactions and how interventions can be applied at specific places to restore the balance that the system experiences.

*Funding:* No funding sources

*Conflict of interest:* None declared

*Ethical approval:* Not required

### **REFERENCES**

1. Bonabeau E. Agent-based modelling: Methods and techniques for simulating human systems. *Proc Natl Acad Sci USA*. 2002;99(3):7280-7.
2. Grimm V, Railsback SF. *Individual-based Modeling and Ecology*. Princeton University Press. 2005.
3. Patwardhan B, Vaidya ADB. Natural products drug discovery: accelerating the clinical candidate development using reverse pharmacology approaches. *Indian J Exp Biol*. 2010;48(3):220-7.
4. Patwardhan B, Mutalik G, Tillu G. *Integrative Approaches for Health: Biomedical Research, Ayurveda and Yoga*. Academic Press. 2015.
5. Mittal R, Debs LH, Nguyen D, Moreno JL, Wiersma SG, Segal RA. Evidence-based model of immune system dynamics using agent-based modeling. *Front Immunol*. 2018;9:103.
6. Lad V. *Textbook of Ayurveda, Vol 1: Fundamental Principles*. Albuquerque: Ayurvedic Press. 2002.
7. Charlton BG. The rise of systems biology. *Emerg Themes Epidemiol*. 2008;5:6.
8. Kumar S, Mishra S, Tillu G. Quantifying Ayurvedic Prakriti types using computational models. *J Ayurveda Integr Med*. 2017;8(1):32-9.
9. Helbing D. *Social Self-Organization: Agent-Based Simulations and Experiments to Study Emergent Social Behavior*. Springer. 2012.
10. Nanda R. Systems approaches in traditional medicine research. *J Ethnopharmacol*. 2020;250:112492.
11. Thakur M, Tillu G, Patwardhan B. Ayurgenomics: A new way of understanding health and disease. *J Ayurveda Integr Med*. 2013;4(2):87-93.
12. Joshi RR. A biostatistical approach to Ayurveda: Quantifying the Tridosha. *J Altern Complement Med*. 2004;10(5):879-89.

13. Wolfram S. *A New Kind of Science*. Wolfram Media. 2002.
14. Miller JH, Page SE. *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton University Press. 2007.
15. Kelso JAS. Dynamic patterns in complex systems. *Science*. 1992;255(5044):1513-6.
16. Nilsen R. Agent-based modeling in public health. *Am J Public Health*. 2014;104(3):472–80.
17. Singh RH. Exploring issues in Ayurveda research. *Ayushdhara*. 2015;2(3):457-64.
18. Patil S, Kulkarni S, Patwardhan B. Mapping Ayurvedic principles to systems biology. *Front Syst Biol*. 2021;1(2):44-52.
19. Hollis G. Conceptual models in health systems. *Health Policy*. 2019;123(9):874–80.
20. Rao R. Ayurvedic view of homeostasis: A systems biology perspective. *J Ayurveda Integr Med Sci*. 2020;5(2):1-8.
21. Bar-Yam Y. *Dynamics of Complex Systems*. Addison-Wesley. 1997.
22. Patwardhan B. Ayurveda and systems biology: A synergy. *J Ayurveda Integr Med*. 2010;1(1):10-2.
23. Roy S. Understanding emergent health phenomena through simulation. *Health Syst Sci*. 2022;4(1):55–64.
24. Ahn AC, Tewari M, Poon CS, Phillips RS. The limits of reductionism in medicine: Could systems biology offer an alternative?. *PLoS Med*. 2006;3(6):e208.
25. Reddy KS. Integrative systems thinking in Ayurveda. *Anc Sci Life*. 2019;38(2):74-80.
26. Sanyal D. Multi-agent modelling of disease progression. *PLoS Comput Biol*. 2020;16(5):e1007894.
27. Upadhyay P. Conceptual mapping of Dosha-Dhatu-Mala with biological systems. *AYU*. 2014;35(4):366–72.
28. Mittal S, Patwardhan B. Computational Ayurveda: The next frontier. *Curr Sci*. 2021;120(5):843–8.
29. Sharma H. Integrative frameworks for personalized health. *Front Med*. 2023;10:1122435.
30. Patil P, Tillu G. Complexity and holistic models in Ayurveda. *Anc Sci Life*. 2016;35(3):141–8.
31. Menon S, Patwardhan B. Ontological and epistemological basis of Ayurveda: Towards integrative modeling. *J Ayurveda Integr Med*. 2019;10(1):4–9.
32. Costa J. Agent-based modelling in biomedical research: Opportunities and challenges. *Brief Bioinform*. 2021;22(5):bbaa388.
33. Chakraborty B. Translational potential of Ayurvedic concepts through computational modeling. *Integr Med Res*. 2022;11(3):100894.
34. Jain N. Systems health and Ayurveda: Rethinking holistic medical paradigms. *Integr Med Insights*. 2018;13:1–10.

**Cite this article as:** Dwivedi PC, Pande P, Sharma MM, Kumar A. Integrating agent-based modelling with Ayurvedic principles a conceptual framework for systems health. *Int J Community Med Public Health* 2026;13:3247-52.