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From Ancestral Knowledge to Artificial Intelligence: Truká and Fulni-ô Epistemologies, Ethnomedicine, Digital Health, and Sustainable Health Futures in Northeast Brazil

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Abstract

Indigenous peoples bear health burdens that biomedicine cannot fix, and these burdens did not appear out of nowhere. They have been produced over five centuries by colonial dispossession, sustained territorial pressure, and a clinical tradition that, for most of that period, has refused to grant Indigenous knowledge epistemic standing. Digital health and artificial intelligence have now arrived in the same villages, primary-care posts, and households. They drag the old questions along with them, only sharper this time: who actually owns the data, whose ways of seeing the world get to count, and what is left of ancestral knowledge once an algorithm gets between the healer and the patient. We write from one specific place — the semi-arid sertão of Pernambuco — and from a long working relationship with two peoples in particular, the Truká and the Fulni-ô, whose health has been tracked for more than ten years now through the PAI INTEGRAL Project (Projeto de Atenção à Saúde Integral Indígena; in English, Project of Accompaniment for Indigenous Health). The PAI dataset covers cardiovascular risk, chronic kidney disease in the elderly, and arboviral seroprevalences so high that they reshape how syndemic risk should be modelled in this region: dengue at 92.5%, chikungunya at 78.2%, and Zika at 95.4%. With that as our regional anchor, we then mapped 285 records across four databases, applying PRISMA-ScR, ENTREQ, and the CONSIDER Statement together. The synthesis is read against three governance frameworks already established in Indigenous-data work — CARE, OCAP, and Free, Prior and Informed Consent — and against one newer idea, cognitive sovereignty. From this, we propose the Ancestral–Digital Ethnomedicine Framework. Seven pairs, in priority order, are as follows: Territory before Data; Community before Platform; Care before Automation; Wisdom before Prediction; Reciprocity before Extraction; Cultural Continuity before Scalability; Sustainable Health before AI. This is not an author checklist. This is an explicit ordering. Indigenous epistemologies come first. Digital tools come after and on the terms Indigenous epistemologies set.

1. Background

1.1 Disparities in Indigenous health and the demand for epistemic acknowledgment

Indigenous peoples comprise approximately 6% of the world’s population; however, depending on the indicator, they bear a two- to four-fold excess prevalence of cardiovascular disease, diabetes, chronic kidney disease, infectious illness, mental distress, and premature death [1–3, 40]. This pattern is rarely accidental. Rather, it is the sediment of five centuries of dispossession, of ancestral landscapes slowly worn down by ranching, irrigation, and mining concessions, and of a clinical tradition that, for most of that period, has been reluctant to count Indigenous knowledge as knowledge at all. Therefore, the implications for present-day public health work are not procedural but conceptual. What needs to shift is not the next intervention but the starting position of health science: Indigenous knowledge belongs in the analytic center — as a coherent way of thinking about illness, healing, and the relations among body, community, and territory — and not, as it has too often been treated, as folklore appended to a biomedical protocol for cultural-competence purposes [4, 11, 23].

1.2 Ethnomedicine as Dynamic Knowledge and Intermedicality

Within ethnobiology and medical anthropology, ethnomedicine designates the shared body of health knowledge, practice, and belief that a given cultural group transmits orally, ceremonially, through apprenticeship, and through accumulated observation of plants, animals, and climate. This category is not reducible to folklore, although it has often been treated as such in the broader literature. Among Indigenous peoples, ethnomedicine is not a frozen

pre-contact remnant; it incorporates new ecological conditions, new materials, and, where useful, elements of biomedicine, without surrendering the relational substrate that biomedicine itself routinely overlooks.

1.3 The digital transformation in Indigenous health: prospects and challenges

The diffusion of digital health technologies over the past decade has been rapid and largely uncontested in policy terms. Telemedicine, mobile health applications, electronic health records, wearable sensors, remote-sensing platforms, and clinical-decision-support systems now constitute standard components of routine clinical practice, a movement accelerated by the COVID-19 pandemic and, in the Brazilian case, formally institutionalized through the Estratégia de Saúde Digital 2020–2028 and Federal Law 14.510/2022. For remote Indigenous regions, the prospective benefits of this transition are not trivial: longitudinal monitoring of chronic conditions, asynchronous access to specialist diagnostics that previously required interurban travel, and new vehicles for health education delivered at scale. The downside is that most of the tools used for this work were not built for these populations. They are based on Western biomedical assumptions. They assume stable connectivity, which is often not the case. They treat the individual as the unit of care, which is not the case in Truká and Fulni-ô health practices. They embed defaults — about language, about bodies, about food — that line up with the populations the platform was designed for, not the populations it ends up serving. They tend to put health authorities inside the platform rather than inside the community [5]. A decade of reviews of ICT-facilitated health interventions in Indigenous communities converges on the same short list of decisive factors: cultural safety, language adequacy, governance, and chronic underfunding [5, 34].

1.4 Ethical considerations of artificial intelligence and Indigenous data sovereignty

Artificial intelligence is now an operational component of contemporary clinical workflows. Large language models, predictive analytics, and machine learning classifiers contribute substantively to diagnostic support in medical imaging and, increasingly, to risk stratification, triage, clinical decision support, and population-level surveillance [14, 18]. However, the training corpora underlying these systems exhibit a recurrent and well-documented gap with respect to the populations on whom such systems are subsequently deployed — indigenous languages, dietary profiles, body-composition distributions, and disease-trajectory data are systematically under-represented or, in many cases, entirely absent. The downstream effect is a form of algorithmic bias that the AI-fairness literature has documented at scale for over a decade [10]. The Buolamwini and Gebru "Gender Shades" audit remains the canonical illustration: commercial computer-vision systems failed disproportionately on darker-skinned and female faces, and the source of the failure was traceable not to the algorithmic architecture but to the demographic composition of the training set. The same chain of reasoning transfers, without modification, to clinical AI systems trained on datasets that exclude Indigenous patients from reference populations. Birhane [10] reads the broader pattern — data and computational labor extracted from the Global South to train models owned and monetized in the Global North — as algorithmic colonialism. Mohamed, Png, and Isaac push the argument from diagnosis to method, sketching what a decolonial AI practice would actually look like: critical technical work, reverse pedagogies, and political solidarity, not ethics-checklist compliance. Bender, Gebru, and colleagues, in the "stochastic parrots" paper, added a related point about scale. More data and parameters, by themselves, do not fix demographic bias. Without governance, they make it worse. Therefore, the question that matters is not technical at all. It is governance: who decides what a model is allowed to do once it leaves the lab? [11]

Indigenous data sovereignty movements have been making the same point for years, and it is a straightforward one. When a dataset is about Indigenous people, Indigenous places, Indigenous lifeways, or Indigenous knowledge, decisions about it — collection, storage, interpretation, reuse — sit with Indigenous authority. They are not delegated to Indigenous participation as an advisory layer added later on. CARE — Collective Benefit, Authority to Control, Responsibility, Ethics — was written precisely to sit alongside the better-known FAIR principles (Findable, Accessible, Interoperable, Reusable). FAIR optimizes data for reuse; FAIR does not ask who benefits or pays the cost. CARE asks both. OCAP — Ownership, Control, Access, Possession — operationalizes that same sovereignty at the level of the First Nation in Canada. Cognitive sovereignty is a more recent extension of this logic into AI itself: communities should govern not only their data but also the epistemic logic and algorithmic reasoning applied to it [11]. Read together with Free, Prior and Informed Consent (FPIC), as set out in the UN Declaration on the Rights of Indigenous Peoples and in the ISE Code of Ethics, these frameworks treat Indigenous peoples as rights-holders, not as the population on which the next pilot will be run.

1.5 Truká, Fulni-ô, and Northeast Brazil as a pivotal case

The Truká and Fulni-ô peoples provide a particularly informative case for thinking through how Indigenous knowledge systems, health outcomes, and emerging technologies come into contact in practice. Both peoples are located in the semi-arid sertão of Northeast Brazil and are among the largest of the more than 30 Indigenous nations currently recognized in the state of Pernambuco. The ecological and historical specifics of each group are distinct; however, taken across a longer time horizon, their trajectories converge around three common processes: resistance, territorial reconfiguration, and prolonged (and frequently antagonistic) engagement with the Brazilian state apparatus.

The Truká, numbering approximately 7,000 individuals, are concentrated on Assunção Island and along the adjacent reach of the São Francisco River, near Cabrobó. Their territoriality is constituted in relation to the river, which functions simultaneously as a subsistence resource, a sacred presence, and an ecosystem under sustained stress from upstream dam construction, the expansion of agribusiness, and the social repercussions of regional irrigation perimeters. The Fulni-ô, approximately 4,000 in number, inhabit Águas Belas and are distinguished within the regional Indigenous landscape by two interrelated cultural features. The first is the continued intergenerational transmission of Yathê, which remains an exceptional case among the Indigenous languages of Northeast Brazil, alongside parallel revitalization efforts among other peoples. The second is the annual Ouricuri retreat, a culturally restricted ceremony whose internal content is protected from external circulation and whose existence we acknowledge in this manuscript only in passing [29]. Neither group is isolated. Neither is assimilated. Both move along a complicated urbanization gradient that puts them in daily contact with municipalities, agricultural markets, federal Indigenous health services, and digital infrastructures — radio, mobile phones, and social media — that have rewired how community health is talked about and lived.

Over the past decade, the PAI Project (Projeto de Atenção à Saúde Integral Indígena), translated into English as the Project of Accompaniment for Indigenous Health, has produced one of the most comprehensive epidemiological profiles of Indigenous cardiovascular and metabolic health in Latin America [1–3] in partnership with the Truká and Fulni-ô communities. The acronym is deliberate. In Portuguese, the three letters stand for *Projeto* (Project), *Atenção [Integral à Saúde]* (Comprehensive [Health] Care), and *Indígena* (Indigenous); together, they spell *pai*, the Portuguese word for *father*. In English, we preserved the acronym and modified only the middle word: *P* for Project, *A* for Accompaniment, and *I* for Indigenous health. The word accompaniment was not chosen randomly. It comes from Latin American liberation thought and Freirean

pedagogy, where care is understood as walking with someone rather than acting upon them. In English, the word does double duty: it captures what *atenção integral à saúde* expresses in the everyday vocabulary of the Brazilian Sistema Único de Saúde (SUS), namely, a longitudinal, holistic, non-hierarchical practice of being with partner communities rather than working on them. The PAI operates simultaneously on three levels. It is an acronym. This is a relational metaphor. This is a methodological commitment. The regional anchoring provided by the present review is what allows the argument that follows to remain grounded in actual evidence — about how cultural continuity, urbanization, environmental exposure, and access to services interact in shaping Indigenous well-being — rather than collapse into abstract speculation about Indigeneity in general.

1.6 Aims and Contributions to Ethnobiological Scholarship

This review has four objectives. First, to place the ethnomedical, ethnobiological, and territorial health experience of the Truká and the Fulni-ô onto the map of the global conversation about digital health and AI ethics — not as a regional curiosity, but as a case the field has been missing. Second, to systematically map the literature across four scales — global, Latin American, Brazilian, and Northeast Brazilian — with particular attention to the SUS and its Indigenous Health Sub-System (SasiSUS), run by SESAI through 34 Distritos Sanitários Especiais Indígenas. Third, to propose an original framework, the Ancestral–Digital Ethnomedicine Framework (ADEF), whose seven domains allow Indigenous principles to set the terms for digital health and AI rather than merely color them. Fourth, to read digital health and AI through the conceptual tools ethnobiology already possesses — ethnomedicine, intermedicality, biocultural diversity, and human–environment interactions — rather than through the narrower biomedical, technical, or philosophical lenses, and to extend the field's engagement with digital technology beyond biodiversity documentation into the territory of algorithmic health futures.

2. The PAI Project: Empirical Foundations

2.1 Genesis and Scope of the PAI Project

The PAI Project — full name in Portuguese as introduced in § 1.5 — is a longitudinal clinical-epidemiological and community-engaged research programme carried out with the Truká and the Fulni-ô of Pernambuco and the neighbouring communities. It began because there was almost no high-quality cardiovascular or metabolic data on Indigenous peoples in northeastern Brazil. For most of the twentieth century, the Brazilian state refused to acknowledge that Indigenous peoples in this region even existed in the ways the people themselves know they exist. From that starting point, the project has produced peer-reviewed evidence across a wide range of areas: cardiovascular risk factors, chronic kidney disease, arboviral exposure, mental health, oral health, drug use, and the implementation of tele-ultrasound and other digital health technologies, all in active partnership with the local Equipes Multidisciplinares de Saúde Indígena (EMSIs) of DSEI Pernambuco. For the purposes of the present review, what matters about PAI is less any single finding than the proof of principle: rigorous epidemiological research conducted *with* (rather than merely *on*) Indigenous communities is feasible in a regional context where Indigenous data have been historically scarce and that such research can be designed to respect the territorial, linguistic, and ceremonial integrity of partner peoples.

2.2 Cardiovascular Observations: Armstrong et al. 2023

Armstrong et al. conducted a cross-sectional cardiovascular risk study that included 411 Truká adults, 414 Fulni-ô adults, and 174 non-Indigenous urban controls from the neighboring Petrolina–Juazeiro region [1]. The principal finding was a marked gap in hypertension prevalence: 18.2% among the Fulni-ô, 33.9% among the Truká, and

33.8% among the urban controls. The protective effect of Fulni-ô persisted even after adjusting for age, sex, body mass index, and smoking. The authors interpret this gap through urbanization and cultural continuity in the region. The Fulni-ô have retained their language, ceremonial calendar, and cohesive dietary and territorial practices. In contrast, the Truká territory is at the receiving end of agribusiness pressure, upstream dam construction, and circular migration to urban areas. We read the evidence of Armstrong et al. as supporting a specific empirical claim, which we state precisely: in this population, cultural and territorial continuity functions as a measurable cardiovascular-protective factor. Any intervention deployed in these communities — digital health platforms, AI systems, future pilots — must therefore be evaluated not only against biomedical endpoints but also against its probable impact on the cultural-ecological substrate that produces protection [1].

2.3 Chronic Kidney Disease in Elderly Indigenous Adults: Gomes et al. 2023

Gomes et al. applied the PAI Project to chronic kidney disease (CKD) in older Truká and Fulni-ô adults. They found something straightforward and worrying: the more urban a community's exposure, the higher its CKD prevalence [2]. The descriptive findings are significant. The methodological findings were more important. Conventional CKD screening was built around non-Indigenous reference populations, and the anthropometric thresholds, dietary protein assumptions, and physical activity baselines that urban biomedicine takes for granted can misclassify risk in semi-arid Indigenous populations whose body composition, traditional diet, and daily physical loads differ systematically from those reference cohorts. The implication for digital health and AI is blunt: any screening or risk-stratification algorithm calibrated on urban non-Indigenous data, deployed without local recalibration and community-controlled validation, will misclassify Indigenous health in ways that look statistically clean but are clinically wrong [2, 10].

2.4 Arboviral exposure and cardiac biomarkers: Nicacio et al. 2024

Nicacio et al. examined the intersection of arboviral exposure and cardiac biomarkers in Fulni-ô individuals in a sample of 174 adults [3]. The seroprevalences they recorded were striking: dengue at 92.5%, chikungunya at 78.2%, and Zika at 95.4%. These numbers are not a coincidence. These reflect the ecology of semi-arid Northeast China. Periodic droughts force households to store water. Stored water sustains *Aedes aegypti*. The same adaptations that buffer droughts open the door to vector-borne diseases. The paper raises a question that is still open: whether chronic, overlapping arboviral exposure, combined with limited cardiological surveillance, produces subclinical cardiac injury on a population scale. For us, Nicacio et al. carry two points forward. First, Indigenous health in Northeast Brazil is syndemic in the strict sense — infectious, non-communicable, and environmental loads co-produce risk and cannot be cleanly separated. Second, an AI-driven syndemic model that considers this complexity seriously will have to be trained on data with this specific epidemiological and ecological texture, not extrapolated from urban disease atlases [3].

2.5 Synthesis of Empirical Evidence

When the three PAI papers are placed side by side, a clear pattern emerges. In this part of Brazil, Indigenous health is not driven by a single mechanism. Several mechanisms act on the same bodies at the same time: cultural continuity, territorial integrity, the urbanization gradient, and ecological exposure. The Truká–Fulni-ô hypertension gap reported by Armstrong et al. [1] is the most arresting finding in the cluster and the easiest to overinterpret. We do not claim that culture alone lowers blood pressure. Cultural continuity travels with the

urbanization gradient, with diet, with water source and water quality, with the kinds of land-use-driven physical activity people actually do, and with whatever social cohesion ceremonial life produces — none of which the paper measured directly. What the differential indexes, on our reading, is the cumulative effect of a culturally structured way of living, which includes ecological, dietary, and relational components together, rather than a clean independent effect of culture as such. With this caveat acknowledged, the broader synthesis still holds. Gomes et al. [2] showed that urbanization acts as a deteriorating force through specific metabolic pathways. Nicacio et al. [3] show infectious and non-communicable disease interacting syndemically in communities whose ecological adaptations produce both resilience and exposure at the same time. Convergent reading: Indigenous health outcomes in Northeast Brazil cannot be reduced to individual biology or behavior. They emerge from an interlocking system of knowledge, territory, food and ceremony. An AI system that optimizes for biomedical endpoints while treating that system as noise risks eroding the very conditions that keep these communities healthy.

3. Methods

3.1 Review design and rationale

This is a critical review of the literature. The aim was not only to catalogue the literature but also to produce a conceptual contribution of our own [13]. The mode was chosen for a reason: the question we asked does not fit a standard effectiveness review. It runs across empirical, theoretical, ethical, and policy evidence, and crosses ethnobiology, ethnomedicine, epidemiology, computer science, ethics, Indigenous studies, and public health all at once. No single review protocol was developed to handle this range. The choice also carries a decolonial commitment: review work is not epistemically neutral, and the assumptions built into the protocol are part of what the protocol ultimately does. The literature search, conceptual coding, and framework development were conducted from June 2023 to January 2026. Drafting and iterative revisions will continue until May 2026.

3.2 Reporting frameworks

Three reporting frameworks were used in parallel: (i) **PRISMA-ScR** (the scoping review extension of PRISMA) for transparent literature mapping, (ii) **ENTREQ** for thematic and qualitative synthesis, and (iii) the **CONSIDER Statement** (Strengthening Reporting of Health Research Involving Indigenous Peoples) for Indigenous health–specific reporting and cultural safety considerations. When recommendations diverged, we prioritized CONSIDER for cultural safety and Indigenous governance items, ENTREQ for thematic synthesis items, and PRISMA-ScR for transparency-of-search and evidence mapping items.

3.3 Search strategy

We searched four databases: PubMed/MEDLINE, Scopus, Google Scholar, and SciELO/LILACS (Latin American and Caribbean Health Sciences Literature). We added snowball searches through the reference lists of the major reviews and grey literature pulled from the WHO, PAHO, SESAI, FUNAI, ABRASCO, GIDA, FNIGC, and ISE. Sixteen structured queries were created from six concept blocks. The first covered Indigenous peoples worldwide and in the Americas. The second covered Northeast Brazil, Pernambuco, the Truká and the Fulni-ô, Yathê, and the São Francisco Valley. The third category covered traditional knowledge, ethnobiology, ethnomedicine, and medicinal plants. The fourth covered Indigenous health and its transitions: cardiovascular, chronic kidney, arboviral, mental health, and ultra-processed foods. The fifth category covered digital health, telehealth, telemedicine, tele-ultrasound, and mHealth. The sixth covered AI, machine learning, large language models, AI ethics, algorithmic

bias, digital colonialism, data sovereignty, CARE, and OCAP topics. Boolean operators combined terms within and across blocks. The searches were conducted in English, Portuguese, Spanish, and French. Time windows varied by topic: no lower bound for classical ethnobiology and ethnomedicine; 1990 onward for empirical Indigenous health; 2000 onward for digital health; and 2018 onward for AI and LLMs. High-quality preprints (bioRxiv, SocArXiv, OSF, Research Square) were admitted only where peer-reviewed evidence was thin, and flagged as such. The search returned 345 records. After de-duplication, 285 remained, and these 285 were included in the screening pool.

3.4 Inclusion and exclusion criteria

We *included* a study if it met any one of five criteria: it reported empirical findings on health outcomes in Indigenous populations of Brazil; it described digital health or AI interventions in Indigenous communities anywhere in the world; it set out frameworks, principles, or ethical guidelines for Indigenous data governance and AI; it analyzed ethnomedicine, traditional knowledge systems, intermedicalidade, or biocultural diversity relevant to Indigenous health; or it examined policy or governance structures for Indigenous health services in Brazil or in a comparable context. We excluded studies that were strictly biomedical with no Indigenous or ethnomedical bearing; AI papers that did not engage health or equity; ethnobotanical inventories with no cultural or interpretive layer; purely *phytochemical or phytopharmacological* studies without ethnographic perspective, since such work falls outside the analytical remit of an ethnomedicine-grounded review; opinion pieces without scholarly grounding; sources that romanticized or essentialized Indigenous peoples; predatory or unverifiable sources; duplicates; and records with fabricated or inconsistent metadata.

3.5 Screening, selection, and quality appraisal

The record screening was conducted in two sequential phases. In the first phase, the titles and abstracts of the 285 unique records were assessed against the inclusion criteria detailed in § 3.4. Records meeting at least one criterion advanced to a second, full-text phase, in which three dimensions were assessed concurrently: substantive relevance to the review's conceptual architecture, methodological quality (judged according to the design appropriate for each evidence stream), and original contribution to the synthesis of the literature. Each retained record was assigned a relevance score on a scale of 0–100 using a multi-component rubric. The components of the rubric included thematic alignment, empirical rigor, geographic specificity, theoretical contribution, and — as a deliberate departure from the standard relevance-scoring template used in conventional systematic reviews — documented evidence of Indigenous authorship, partnership, or governance in the source. Records with scores above the prespecified threshold of 40 were retained for citation. The top scorers formed a primary citation set. The three principal PAI publications [1–3] were treated *a priori* as anchor texts, given their direct empirical engagement with the Truká and Fulni-ô communities.

3.6 Conceptual coding framework

The retained literature was coded along nine analytical axes, which were specified prior to extraction. The first axis — scale — was operationalized at five nested levels: global, hemispheric (Americas), national (Brazil), regional (Northeast Brazil), and local (Pernambuco), terminating in the focal Truká–Fulni-ô level. Type of knowledge covered Traditional Ecological Knowledge (TEK), ethnomedicine, ethnobotany, and the oral, embodied, and community health forms in which knowledge actually moves. Cultural meaning tagged how each source treated health, illness, healing, plants, food, the body, territory, ancestry, language, and intergenerational transmission were tagged. The health domain covered cardiovascular, renal, infectious, mental, oral, maternal, and child health. The technology domain covered digital health, artificial intelligence (AI) and machine learning, telehealth, and

governance. The ethical domain encompasses FPIC, CARE, OCAP, cultural safety, and AI ethics. Two further axes carried the human-ecological and forward-looking content — territory, biodiversity, food systems, and climate on one side, and sustainability and planetary health on the other. The ninth axis performed most of the analytical work. We called it the claim level. Level 1 marked direct PAI/Truká/Fulni-ô evidence is marked. Level 2 indicates regional indirect evidence. Level 3 includes conceptual or theoretical material. Level 4 indicates forward-looking inference. The point of coding was to keep direct empirical claims about the Truká and Fulni-ô from quietly merging with broader conceptual claims at the page level.

3.7 Framework development methodology

The framework was developed from the coded synthesis. It was not imposed. Seven points of recurring friction kept appearing between Indigenous epistemologies and the working assumptions of digital health and AI: territory, community, care, wisdom, reciprocity, cultural continuity, and sustainability. For each, we wrote four things: the Indigenous principle at stake, the digital health counterpart it must be reconciled with, the risk that comes when AI proceeds in the absence of that principle, and an integration pathway. We checked the name. Across the review window (June 2023 – January 2026), systematic searches across search engines, document repositories, and academic databases revealed no prior use of the "Ancestral–Digital Ethnomedicine Framework" or near variants.

3.8 Cultural-safety protocol

Some Fulni-ô spiritual practices — the annual Ouricuri retreat above all — are protected and not for external circulation. Even when academic sources have published parts of them, we do not reproduce ritual details, sacred names, or culturally restricted material in this paper. Where it is unavoidable for the argument, we refer in broad terms to the existence of the practice, with citation, and stop there. The same caution applies to the restricted Truká knowledge. The protocol follows the ISE Code of Ethics and cultural safety provisions of the CONSIDER Statement.

3.9 Limitations of the review

A few limitations should be on the table. The first is methodological in nature. A critical review is the right tool for the kind of conceptual synthesis we wanted to do, but it does not carry the standardized risk-of-bias appraisal that a systematic review of interventions would. The second is temporal. The Indigenous digital health and AI literature is moving fast, and anything published after our cutoff in January 2026 falls outside the window. The third is scope. The empirical specificity obtained from focusing on the Truká and the Fulni-ô limits direct generalizability to other Indigenous contexts. Transfer is possible. It is not automatic. The fourth is governance (G). In this first publication phase, the framework has not yet been formally validated by Truká and Fulni-ô representatives. This is the purpose of Phase 2. The fifth factor is visibility. Grey literature, Indigenous community reports, and oral knowledge sources that are not indexed in major academic databases are likely to be under-represented in the final reference set, with knock-on consequences for the share of Indigenous-authored voices in our citations. We return to this point in § 7.5.

4. Worldwide Overview of Indigenous Digital Health and Artificial Intelligence

4.1 Digital health interventions in Indigenous communities

International evidence on digital health for Indigenous communities is mixed. Some pilots have been implemented. Many have not. The field has slowly come around to what the communities themselves have been saying all along — that culturally safe design is the precondition for any of this working, not a feature added on at the end [5, 16]. Across Canadian First Nations, Australian Aboriginal and Torres Strait Islander communities, and Māori communities in Aotearoa New Zealand, the dominant modalities are telehealth, mHealth, and electronic health records, and most projects never get past the pilot stage [5]. Culturally safe eHealth frameworks have emerged because the existing best-practice guidelines were not written with Indigenous priorities, cultural protocols, or community governance in mind [15]. The DREAM-GLOBAL trial is a useful counterexample: culturally adapted SMS-based blood pressure management can deliver real clinical outcomes in Indigenous communities, but only when the adaptation is co-designed with the community rather than dropped in from outside [6]. In remote settings, the constraints repeat themselves: limited broadband, unreliable electricity, weak technical support, and the requirement that the approach actually fit the geography and culture of each particular community [20]. The interventions that last are those that build capacity within the community rather than importing a finished tool [21]. Even in non-Indigenous Brazilian urban primary care, recent digital health platform deployments have surfaced usability, equity, and language gaps, which signal that any adaptation for Indigenous communities will require a substantially deeper redesign than mainstream platforms have so far attempted [12]. The Aotearoa implementation work makes the opposite case in the affirmative: participatory implementation grounded in Māori governance can produce strong uptake and acceptability [28].

4.2 AI applications in Indigenous health

Thus far, AI in Indigenous health is mostly aspirational. The published literature is full of frameworks, ethical guidelines, and conceptual proposals; implementations actually evaluated against community-defined outcomes remain far thinner on the ground [8, 9, 14, 16, 35]. For Canada specifically, Khan, Galea and Mendez [14] laid out a five-step sequence: profile the community first; assess local digital readiness; let the community set which health concerns matter most; deploy virtual care programmes in a culturally calibrated way; and use AI itself in the outcomes-evaluation phase. The Two-Eyed Seeing approach, articulated by Mi'kmaq Elder Albert Marshall, has been adopted as an epistemological foundation for AI in Indigenous health on the principle that algorithmic systems should complement Indigenous ways of knowing, rather than displacing them [4]. The familiar AI-fairness concerns about unrepresentative training data and miscalibrated clinical-decision thresholds [4, 8, 10, 11] hit especially hard in imaging-AI projects aimed at remote and Indigenous settings, where the populations the models were trained on diverge substantially from the populations the models are then used on. The African literature on AI in health is currently stronger on malaria surveillance, diagnostics, and system optimization than on evaluated systems that explicitly encode Indigenous diagnostic categories [38], a gap that reinforces the broader call across the Indigenous-AI literature for AI architectures governed by Indigenous data sovereignty and CARE principles so that community knowledge systems, cultural validity, and locally defined priorities shape design and evaluation, rather than treating Indigenous knowledge as extractable training material [8, 9, 25, 35–37]. This is echoed by parallel scholarship on diagnostic sovereignty in AI-enabled African healthcare systems [32]. Across this body of work, the underlying task is the same: ensuring that AI ends up as a tool under Indigenous governance, not as another route by which epistemic colonization is automated [11, 23].

4.3 Data sovereignty frameworks: CARE, OCAP, and cognitive sovereignty

Indigenous data sovereignty has been consolidated as the foundational principle for ethical engagement with digital health and AI in Indigenous contexts. The CARE Principles for Indigenous Data Governance — Collective Benefit, Authority to Control, Responsibility, Ethics — were drafted by the Global Indigenous Data Alliance to sit alongside the better-known FAIR principles that have come to dominate the open-science conversation [9, 25]. FAIR optimizes data for scientific reuse. It does not, by itself, take on the power asymmetries or the Indigenous rights, and that gap creates the kind of extraction in which the researcher ends up with a paper and the source community ends up with nothing. A systematic review of responsible stewardship of research and health data from Indigenous communities identified 41 frameworks, most of which converge on the same point: intentional engagement with Indigenous researchers and communities minimizes harm and makes benefit possible [9]. OCAP — Ownership, Control, Access, and Possession — articulated by the First Nations Information Governance Center, operationalizes the same sovereignty at the community level through concrete governance mechanisms. Cognitive sovereignty is a newer extension: communities should control not only their data but also the epistemological frameworks and algorithmic logics that are applied to that data [11]. Russ-Smith and colleagues spell out the relational responsibilities of researchers and institutions when working with Indigenous data in AI development [10]. Together, these frameworks form the governance architecture that any digital health or AI deployment in Truká and Fulni-ô contexts must respect [7–11, 25].

4.4 Gaps and opportunities

Several gaps remain in the published work. The literature is still concentrated in the Global North — Canada, Australia, Aotearoa New Zealand, and the United States — and the Latin American Indigenous experience is sparsely represented [5]. Most existing frameworks operate at the principle level and stop before reaching community-applicable implementation protocols. The intersection of ethnomedicine and digital health is, for practical purposes, untheorized. How traditional healing knowledge should interface with digital platforms, clinical decision support, and LLMs are still open questions. Empirical evaluations of AI applications in Indigenous health are nearly absent. The field is still anchored in speculative framework-building rather than community-assessed outcome data. This review is shaped by these factors. By anchoring the analysis in the specific empirical context of the Truká and the Fulni-ô, drawing on PAI Project evidence, and proposing a framework that bridges ethnomedical knowledge and digital health governance, we offer a partial response to a gap that runs through both the Indigenous health literature and the digital health literature [8, 13].

5. The Context of Latin America and Brazil

5.1 The Unified Health System and the Indigenous Health Subsystem

Brazil's Sistema Único de Saúde (SUS), established under the 1988 Constitution, guarantees universal healthcare as a constitutional right. The Subsistema de Atenção à Saúde Indígena (SasiSUS) was created by Federal Law 9.836/1999 and has been implemented since 2010 by the Secretaria Especial de Saúde Indígena (SESAI). It covers 34 Distritos Sanitários Especiais Indígenas (DSEIs). Each DSEI coordinates primary care through Equipes Multidisciplinares de Saúde Indígena (EMSIs) based at community health posts (Postos de Saúde), with referral pathways into the Casas de Apoio à Saúde Indígena (CASAIs) and from there into the secondary and tertiary tiers of the wider SUS. The DSEI Pernambuco is the one that serves the Truká and the Fulni-ô. The institutional design is on paper. The day-to-day reality is more difficult. SasiSUS faces chronic underfunding, high staff turnover, real geographic-access barriers, weak integration of traditional medicine, and management-information systems —

SIASI being the main one — that capture biomedical metrics while leaving Indigenous health paradigms, ethnomedical classifications, and ceremonial factors invisible to the data [1].

5.2 Ethnomedicine in Brazilian Indigenous Health Policy

Brazilian policy recognizes traditional medicine on paper through two main instruments. The Política Nacional de Atenção à Saúde dos Povos Indígenas (PNASPI, 2002) commits the state to respect for traditional healing systems. The Política Nacional de Práticas Integrativas e Complementares (PNPIC, 2006) sets up institutional space for non-biomedical therapies inside the SUS. The text and practice have not kept up with each other. Traditional medicine is generally considered a supplement rather than a peer knowledge system. The ethnographic work on intermedicalidade among the Truká shows how the negotiation actually plays out: community members move back and forth between biomedical services and traditional healers depending on the illness, severity, social setting, and cultural protocol in play [12]. The Fulni-ô have built education into a vehicle for strengthening traditional medicine, with community-led initiatives passing ethnobotanical knowledge and healing practices down to younger generations as a form of cultural resistance. Across the broader semi-arid Northeast, Indigenous women healers — including those in the neighboring Kantaruré community — hold ancestral knowledge of medicinal plants and tie conservation tightly to health promotion, refusing the biomedical separation between environmental and human health [23]. In their ethnobotanical study of Kantaruré women, Lima and Nunes [24] recorded the cajueiro (Anacardium occidentale L.) and umbuzeiro (Spondias tuberosa Arruda) as the most-cited plants for women's reproductive health, used for menstrual regularity and a wider range of gynecological purposes. The same authors also recorded the continued medicinal use of aroeira-do-sertão (Myracrodruon urundeuva), baraúna (Schinopsis brasiliensis), and angico (Anadenanthera colubrina), three Caatinga species now listed as threatened with extinction in regional flora assessments [30]. The following point is one that regional literature keeps repeating: the survival of Indigenous ethnobotanical knowledge and the survival of the biome itself are bound together. Similar Caatinga pharmacopoeias have been documented among other Indigenous groups of the Northeast semi-arid, although a primary inventory for the Truká and the Fulni-ô remains a documentation gap that this review does not try to fill [19]. Truká-specific zootherapeutic knowledge has been recorded alongside the plant pharmacopoeia in 137 applications across 21 animal species, with substantial inter-village variation. This variation is a reminder of how strongly the physical environment and intercultural contact shape what survives inside a traditional medical system [19]. The Truká and Fulni-ô pharmacopoeias remain poorly documented in international literature. We do not attempt to produce a primary inventory here. We insist that any digital documentation tool or AI-assisted decision-support system deployed in these communities must engage these knowledge systems at the level of species, preparation, dosage, and ritual context, not via generic plant-name look-ups. Recent work documents zootherapeutic and phytotherapeutic adaptations among migrating Indigenous groups and shows that ethnobiological knowledge is mobile and adaptive, even under displacement [19]. Other contributions point to the wealth of ethnosaberes across the Amazonian and Northeastern landscapes — a wealth that health policy still does not engage on its own terms [27].

5.3 Digital health expansion in Brazil

Brazil has substantially adopted digital health technologies. The *Estratégia de Saúde Digital* 2020–2028 establishes a national roadmap, the *Rede Nacional de Dados em Saúde* (RNDS) provides interoperability infrastructure, and the COVID-19 pandemic catalyzed the establishment of a permanent regulatory framework for telemedicine through Federal Law 14.510/2022. However, this expansion has been uneven. Most of this has occurred in urban settings, with limited attention to Indigenous needs and rights. Implementation studies of digital

health platforms in Brazilian primary care, including the *EndoConnect* platform for endometriosis care, have revealed challenges in usability, equity, and cultural appropriateness, even in non-Indigenous urban settings. This suggests that adaptation for Indigenous communities requires a substantially more profound redesign [23, 24]. The digital divide affecting Indigenous territories—limited connectivity, inconsistent electricity, and the absence of bilingual or multilingual digital literacy programs —creates structural barriers that technology alone cannot overcome. The PAI Project's experience with tele-ultrasound [40] demonstrates that hybrid models, in which digital infrastructure supports rather than substitutes the EMSI's relational work, can extend specialized diagnostics into Truká and Fulni-ô communities while preserving their trust.

5.4 The Discrepancy in AI Governance

Brazil's AI governance work is currently moving through PL 2338/2023, the proposed Legal Framework for Artificial Intelligence. The bill puts forward principles familiar from comparable regimes elsewhere — transparency, non-discrimination, human oversight, privacy protection — but it does not name Indigenous data sovereignty, does not require FPIC for AI applications that draw on Indigenous knowledge, and does not engage the specific risks algorithmic bias creates for Indigenous communities. The Estratégia Brasileira de Inteligência Artificial (EBIA), which is supposed to set the national direction, prioritises economic competitiveness and innovation; Indigenous rights inside the AI sector are not on the priority list there either. This results in a regulatory gap. AI systems can be deployed in Indigenous health settings in Brazil without specific safeguards for cultural knowledge, collective data rights, or community governance authority. The gap matters more here than in some other jurisdictions because Brazil already runs an extensive Indigenous health data infrastructure in SIASI, meaning the inputs an AI system would need are already in the database, with no clear consent or benefit-sharing architecture sitting on top [25].

5.5 Northeast Brazil Indigenous communities: Truká and Fulni-ô in context

The semi-arid Northeast — the sertão — is home to Indigenous peoples whom the national Indigenous movement and academic literature have historically under-counted, since both have concentrated on Amazonian populations. The sertão peoples cut across the stereotype that the country uses to recognize Indigeneity. They are often phenotypically mixed in nature. Many no longer speak the language their ancestors spoke (the Fulni-ô, with Yathê, are notable exceptions). The landscape they live in has been shaped by centuries of colonial ranching, irrigation, and agriculture rather than being left as dense forest. This does not imply that their ethnic identity is weaker. The robustness of these peoples' territorial claims, ritual practices, and knowledge systems is their survival under continuous pressure, not a relic of isolation.

The Truká people, on Assunção Island and along the São Francisco River near Cabrobó, sustain a riverine ethnomedicine in which the river itself is treated as a healing presence. Their Toré, prayers, and herbal practices run alongside active engagement with biomedicine, and day-to-day community health is organized through a dense intermedical network of healers, *rezadeiras*, *parteiras*, and EMSIs [12]. The Fulni-ô, in Águas Belas, sustain Yathê as a vehicle of intergenerational ethnobotanical and ceremonial transmission and uphold the Ouricuri retreat as a non-negotiable axis of cultural life, whose internal content we deliberately do not detail here [29]. Both peoples participate in regional and national Indigenous health policy through articulations such as the *Articulação dos Povos Indígenas do Nordeste, Minas Gerais e Espírito Santo* (APOINME) and related regional Indigenous organizations and have been long-term partners of the PAI INTEGRAL Project. The cardiovascular gradient documented by Armstrong et al. [1], the renal findings of Gomes et al. [2], and the arboviral seroprevalence of

Nicacio et al. [3] together render these communities a critical case for examining how digital health and AI might either support or undermine the cultural continuity that the evidence suggests is health protective.

6. The Ancestral-Digital Ethnomedicine Framework (ADEF)

6.1 Justification and Novelty

Existing frameworks for Indigenous digital health do important things, but each stops short of where we need to start. CARE, OCAP, Two-Eyed Seeing, the Five-Steps model, and various cultural safety guidelines do not theorize the *ethnomedicine–technology* interface [4, 9, 14, 15]. CARE governs data relationships, OCAP operationalizes community control of data, cultural safety addresses provider behavior, and Two-Eyed Seeing articulates an epistemological orientation. However, none of these frameworks provide a domain-by-domain articulation of how traditional healing knowledge systems should interact with AI-driven clinical decision support, how digital platforms should accommodate Indigenous ontologies of health and illness, or how the scalability imperative of technology development conflicts with the cultural specificity required by ethnomedicine. A recent and widely cited article on digital technologies in ethnobiology [13] addresses methodological opportunities and ethical challenges, but its focus remains on biodiversity documentation rather than health applications. What is missing is a framework that simultaneously (a) places Indigenous epistemological authority at the center, (b) addresses the specific risks that AI and digital platforms pose to ethnomedical knowledge, (c) provides actionable guidance across multiple implementation domains, and (d) remains anchored in empirical evidence on Indigenous health determinants. The proposed Ancestral–Digital Ethnomedicine Framework aims to address this gap. The originality of the framework's designation was verified through systematic web and database searches, and no prior use of the exact term was found.

The framework comprises seven domains. Each is set up as a relation of *priority*—an Indigenous principle that takes precedence over its digital health counterpart—together with a *forward-looking* risk analysis of disembedded AI and an integration pathway. Throughout this section, we make explicit the distinction between empirical observations and forecast-grade claims: the "Indigenous principle" elements are grounded in documented ethnographic and PAI Project sources [1–3, 12, 29], whereas the "Risk of disembedded AI" subsections function as **Claim Level 4** propositions in the sense articulated in our Methods (Section 3.6) — they are conceptual forecasts of plausible failure modes for AI/digital health integration in Indigenous contexts, not records of documented adverse events. The seven domains are interrelated and non-hierarchical; they mutually constrain and inform each other, and the framework is designed for holistic implementation.

6.2 Domain 1: Territory before Data

For the Truká, the São Francisco River is not a feature on the map. It is a living entity. It is simultaneously food, a sacred presence, and the place where the body recovers [10, 12]. **The Ouricuri retreat plays an analogous role for the Fulni-ô: it is the site where healing knowledge is transmitted, its meaning is inseparable from the place, and its content is protected from outside circulation** [11, 29]. **In both cases, health is held inside the territory — in the land itself, in its waters, in its plants, in the ancestors, and in the spiritual presences that belong to particular sites.**

Digital health counterparts include geospatial health data, environmental monitoring, territorial health mapping, and location-based services.

Risk of disembedded AI. When AI systems pull territorial health data — environmental exposures, geographic disease patterns, and the locations of medicinal plants — without recognizing Indigenous territorial sovereignty, what was sacred and relational becomes a data layer available to anyone with the credentials to query it. Predictive models that map disease risk to coordinates can expose information that should not have left the community or be used downstream to justify interventions that nobody requested.

Integration pathway. Digital territorial health tools are under community land councils. Indigenous spatial knowledge — sacred sites, medicinal-plant locations, seasonal healing calendars — should sit at the primary data layer, not as a courtesy overlay on biomedical geospatial frameworks. AI applications that handle territorial health data require community-controlled access protocols and should not be deployed without the FPIC [8, 10].

6.3 Domain 2: Community before Platform

Health decisions in both communities are made collectively. They sit inside kinship, ceremonial obligation, and community governance, and the people whose voices count run well beyond the patient: extended family, community healers, and spiritual practitioners whose authority comes from cultural protocol rather than from a credential issued in a hospital.

Digital health counterparts include health platforms, patient portals, electronic health records, and telemedicine interfaces, all of which are designed around the individual user.

Risk of disembedded AI. Platforms built around individual accounts, records, and one-to-one clinical encounters fragment a practice that is not individualized. Health apps that talk to one person at a time can hollow out community healing networks and quietly hand collective decisions over to algorithmic recommendations.

Integration pathway. Platforms must accommodate collective decision-making through family or community access models, by giving community healers real roles inside the workflow, and by adopting governance structures that resemble Indigenous authority rather than a SaaS dashboard [15, 21]. Community councils must maintain authority over whether a platform is adopted, how it is modified, and when it shuts down.

6.4 Domain 3: Care before Automation

Healing in these communities is a relational process. It occurs through the healer's presence — through touch, voice, prayer, and the culturally specific context that surrounds the encounter — and the therapeutic effect cannot be cleanly separated from the relational conditions under which it is delivered.

Digital health counterparts include automated health assessments, AI chatbots, algorithmic triage, remote monitoring, and clinical decision support systems.

Risk of disembedded AI. Automation that replaces a healer with an interface strips out the relational dimension that does much of the therapeutic work in Indigenous contexts,and triage systems that route patients toward biomedical interventions and ignore Indigenous healing pathways will erode community trust and route care around the very practitioners the community relies on.

Integration pathway. AI and automation should support human healers — biomedical and traditional — and not stand in for them. Technology should extend what healers can do (a useful example is flagging pharmaceutical interactions with herbal remedies for traditional practitioners) while keeping relational care at the center of treatment.

6.5 Domain 4: Wisdom before Prediction

Indigenous knowledge systems generate categories for which the AI literature has no real equivalent. We call it wisdom: contextual, relational, cumulative, built across generations, and held together by observation, spiritual insight, and the unbroken chain of people willing to teach it. Wisdom is not a collection of data points. This does not reduce to a statistical correlation.

Digital health counterparts include predictive analytics, machine learning algorithms, risk stratification models, and population health projections.

Risk of disembedded AI. AI prediction systems that claim to forecast Indigenous health outcomes from data patterns alone can quietly erode the long observational record that the community already has. Predictive models that label things as "risk factors" in Indigenous communities without understanding their cultural and ecological contexts will pathologize adaptive behavior or miss the protective practices that the algorithm cannot see [1].

Integration pathway. Predictive systems should consider Indigenous observational knowledge as validated input, including traditional environmental indicators of disease seasonality, dietary knowledge about health-protective foods, and community-recognized early signs of illness. Algorithmic outputs should be passed to Indigenous knowledge holders for interpretation rather than being treated as recommendations in their own right [4, 14].

6.6 Domain 5: Reciprocity Prior to Extraction

The principle of reciprocity is applied. You do not take without giving, you do not benefit without contributing, and you do not extract without returning. The principle applies across the board — to relationships with land, nonhuman beings, and knowledge itself, not only with other people.

Digital health counterparts. Health data collection, biobank development, research partnerships, and technology rollouts generate downstream value.

Risk of disembedded AI. AI systems are data-hungry by design, and this hunger creates strong incentives to keep extracting more health data, biological samples, documented traditional knowledge, and behavioral traces from Indigenous communities to train algorithms whose payoff accrues to someone else (a research group, company, or government department) [9].

Integration pathway. Every data collection effort must produce concrete, community-defined benefits that flow back to the source. AI systems trained on Indigenous health data must be partially or fully owned by the communities that contributed the data, with benefit-sharing agreements that name intellectual property, commercial applications, and knowledge products. Research partnerships should demonstrate reciprocity through capacity building, infrastructure investment, and a real plan for returning the knowledge generated [7, 9].

6.7 Domain 6: Cultural Continuity Prior to Scalability

Language, ritual, healing practices, and the wider knowledge system are not decorative features of Indigenous identity. They are its substrate, and as the PAI cardiovascular data suggest [1], **they may also operate as independent determinants of health. This moves cultural continuity out of the "soft" column. This is not a value to be balanced against health service delivery. It belongs inside the health conversation from the beginning.**

Digital health counterparts. Scalable platforms, standardized interfaces, interoperable systems, and replicable intervention models.

Risk of disembedded AI. The pressure to scale a digital health product drives standardization, which tends to erase cultural specificity of the product. A platform marketed as "culturally neutral" or "universally applicable" carries majority-culture assumptions; it will render Indigenous practices either invisible or incompatible with its interface. AI systems optimized for scalability precisely resist the localization required for cultural continuity.

Integration pathway. Design must prioritize cultural specificity over scalability, which means accepting that what works for the Fulni-ô may not work for the Truká or any other Indigenous group. The practical implications are community-specific design processes, language-appropriate interfaces (including Yathê for the Fulni-ô when consent is given), and governance structures in which communities shape technology to the culture rather than vice versa [17, 31].

6.8 Domain 7: Sustainable Health before AI

Health sustainability is the ability of a community to maintain itself across generations through ecological, social, spiritual, and physical practices. It outranks technological innovations. Indigenous communities have maintained their health for millennia without digital tools. AI is one of many options. This is not a requirement.

Digital health counterparts. AI-driven health optimization, precision medicine, algorithmic health management, and technology-dependent care models.

Risk of disembedded AI. Technological dependence results in fragility. Communities that rely on AI-driven healthcare are subject to connectivity, software updates, corporate decisions, and external technical expertise. When AI fails — and AI systems do fail — communities that have not retained traditional knowledge lose both lines of defence at once [20].

Integration pathway. Digital health and AI should be treated as adjuncts to Indigenous health knowledge and practice, rather than as replacements. Technology should extend traditional competencies rather than erase them. Communities should maintain the capacity to function fully without digital systems and use technology only when it clearly improves outcomes without creating dependency [5].

6.9 Implementation pathways

The seven domains are not independent items on the checklist. They are interrelated and must be implemented together rather than one at a time. The implementation requirements are specific. Community-led governance bodies with real decision-making power over technology choices. FPIC procedures before deployment. Capacity building within the community so that Indigenous technical competence grows. Iterative co-design that prioritizes Indigenous design principles. Ongoing evaluation against community-defined well-being metrics, not vendor-defined KPIs. And — just as important — exit strategies are needed. Clauses that allow communities to stop using a system without losing care continuity. Data portability. Critical clinical operations that remain sustainable through non-digital means include a defined timeline for vendor disengagement. Several technical architectures support this position. Federated learning keeps the data inside the source community while still allowing models to learn across communities. Differential privacy and homomorphic encryption add cryptographic protection to aggregated patterns. XAI overlays make model outputs interpretable through feature attribution rather than handing them down as opaque verdicts. Synthetic data generation is another possibility, with the caveat that a

biased generator reproduces the biases of its training data. Regulations are moving in parallel with technology. The EU AI Act will enter into force in August 2024. Its Article 5 prohibitions, including biometric categorization that infers sensitive attributes such as race, ethnicity, or religious belief, became applicable in February 2025. The Annex III obligations (documentation, fundamental-rights impact assessment, human oversight, and post-market monitoring) will apply to clinical decision-support systems from August 2026. If Brazil's PL 2338/2023 aligns with this architecture, comparable protections may eventually extend to Indigenous data applications. The framework as a whole refuses the pilot-project model in which external researchers deploy a tool, gather data, publish findings, and leave, leaving the community without sustained technology and without returned knowledge [7, 9, 11].

The AI fairness and privacy-preserving machine-learning literature already provides technical architectures that align well with the framework domains. **Federated learning** — in which model training is distributed to local data holders so that raw data never leaves the source environment and only mathematical updates are aggregated — operationalizes Domain 1 (Territory before Data) and Domain 5 (Reciprocity before Extraction) by allowing Indigenous communities to retain physical and jurisdictional custody of clinical-epidemiological data while still contributing to broader model performance [9, 11]. **Differential privacy** and **homomorphic encryption** add layers of cryptographic protection that can render community-level patterns useful for aggregate analysis without exposing individuals or culturally sensitive variables. **Explainable AI overlays** address the capacity asymmetry implicit in Domain 4 (Wisdom before Prediction): rather than asking Indigenous knowledge holders to interpret opaque transformer outputs, explainability tooling can render model outputs in terms of feature attributions and counterfactual reasoning that lay translators and traditional practitioners may engage with. **Synthetic data generation** is a fourth possibility for sensitive Indigenous health domains, although it brings its own risks of biased generation if the underlying model is colonial in the training data.

Simultaneously, the regulatory side is consolidating at the same time. The **European Union Artificial Intelligence Act** (which entered into force in August 2024, with prohibitions effective February 2025 and most high-risk obligations applying from August 2026) classifies a number of practices under its Article 5 as outright prohibited, including biometric categorization systems that infer sensitive attributes such as race, ethnicity, or religious belief — provisions that bear directly on AI applications that might profile Indigenous individuals. Health AI systems used for clinical decision-making, triage, or risk stratification fall under Annex III as high-risk, triggering obligations for documentation, fundamental rights impact assessment, human oversight, and post-market monitoring. If Brazilian regulations align with this architecture through *PL 2338/2023*, comparable protections for Indigenous data use may become available domestically. The framework explicitly rejects the "pilot project" model in which external researchers deploy technology, collect data, publish results, and move on, leaving communities with neither sustained technology nor returned knowledge. Instead, it requires long-term relational commitment, resource transfer, and genuine power-sharing that transform the structural conditions enabling both health disparities and epistemic marginalization [7, 9, 11].

7. Discussion

7.1 Synthesis across evidence domains

The review draws on several evidence domains — clinical epidemiology from the PAI Project, technology assessment from the digital health literature, and ethical governance from the data sovereignty work — and builds a single argument about how Indigenous epistemologies relate to emerging health technologies. The synthesis

surfaces a central tension in this study. The knowledge systems, territorial relationships, and cultural practices that PAI evidence flags as health-protective are precisely the ones most easily disrupted by poorly designed digital health and AI applications. The Fulni-ô's lower hypertension prevalence, which the data tie to cultural continuity, implies a different evaluation rule for the interventions deployed here. The question is not only what direct health outcomes an intervention produces. The question is also what it does to the cultural-ecological framework that sustains health in the first place. This reading lines up with the growing literature on cognitive sovereignty, where the claim is that communities should govern not just their data but also the epistemological frameworks through which health is understood and managed [11].

7.2 Contribution to Ethnobiological Scholarship

This review contributes to ethnobiology in four ways. First, it extends the field's conversation about digital technologies in health. AI's interaction with healing knowledge raises a different set of ethical and epistemological problems than AI's interaction with species occurrence data, and the field is only beginning to engage that difference. Second, it offers empirical grounding through the PAI Project — grounding that other frameworks in this space have lacked — so the principles articulated here can be checked against quantifiable health outcomes rather than being theoretical. Third, it brings a Latin American Indigenous experience into a conversation that has been largely shaped by Canadian, Australian, and Aotearoa perspectives [5]. Fourth, it operates at a level of specificity meant to make the framework empirically testable, rather than remaining at the principle level where most current governance frameworks rest. We read the contribution as consistent with — though more narrowly health-focused than — the comprehensive twenty-year framework for ethnobiology set out by Albuquerque, Pieroni, and colleagues [39], and complementary to recent ethnobiological work on digital technologies and methodological-ethical implications [13]. This manuscript operationalizes that agenda at the specific intersection of ethnomedicine and AI.

7.3 Implications for policy and practice

This review points to concrete policy implications. If SESAI's digital health work is to expand within Brazilian health policy, it will require Indigenous-specific AI governance mechanisms, which are absent from both the SUS digital health strategy and the proposed AI legislation. The proposed architecture has three elements. The first is data-governance bodies at the DSEI level, run by Indigenous community representatives with authority over every AI application that touches Indigenous health data. The second is the National AI Strategy (EBIA), revised to include explicit measures for Indigenous data sovereignty along CARE lines. Third, digital health interventions in Truká and Fulni-ô communities should be co-designed through participatory processes, overseen by community health councils, and evaluated against Indigenous-defined health indicators — cultural continuity, territorial integrity, and knowledge transmission — alongside standard biomedical outcomes. The framework is designed to be transferable. Other Indigenous communities can adapt it to their own cultural, ecological and political contexts [7, 8].

7.4 Anti-romanticization and anti-technophobia

We have refused two positions on the way to this argument, and both refusals matter for the balance of what follows. The first refusal: we have not painted Truká or Fulni-ô knowledge as timeless or pre-modern. The evidence we draw on shows communities in active negotiation with the Brazilian state, agribusiness, regional markets, social media, and the clinical infrastructure of the PAI Project itself. These are diverse, contemporary peoples — and in the Fulni-ô case, peoples whose linguistic and ceremonial distinctiveness has been actively misrepresented by the dominant national narrative for longer than that narrative has existed. The second refusal is

that technophobia has not been adopted. Digital health and AI can be used for useful work. They can improve health education. They can be translated across linguistic divides. They can extend diagnostic access to populations that biomedicine has historically reached late or not at all. They can longitudinally monitor chronic diseases. They can support community-controlled curation of Indigenous knowledge, provided that reciprocity, sovereignty, cultural safety, and clear ethical limits govern the deployment. Our critique is aimed at AI that is unregulated, extractive, disembedded, and culturally unsafe. It is not aimed at technology development.

7.5 Limitations

This review has several limitations, beyond those listed in § 3.9. The Ancestral–Digital Ethnomedicine Framework is anchored in literature and empirical evidence, but it has not yet been validated through community consultation with Truká and Fulni-ô knowledge holders. This validation is what Phase 2 is for. The seven domains are architecturally comprehensive. Whether they capture every dimension that matters in a particular Indigenous context remains an open empirical question. The review's reliance on academic literature also means that Indigenous voices expressed through non-academic channels are probably under-represented. Our reference set currently sits at roughly 12% Indigenous-authored or Indigenous-organization-authored — below the benchmark we would want for work of this kind. We note this transparently here so that subsequent work can correct it. Finally, the pace of AI development means that the specific technological risks we identify here will move faster than governance frameworks can respond, so the framework will need ongoing adaptation rather than a one-time fix.

8. Future directions

8.1 Research Agenda

This framework opens up several research directions. The obvious first step is validation studies. Do communities working under framework-aligned technology governance show better health outcomes and stronger cultural continuity than those exposed to conventional digital health implementation? That is testable. Comparative work — Truká/Fulni-ô against Amazonian, Southern Brazilian, or pan-Latin American Indigenous communities — would show which of the seven domains need to be reshaped for each context and which travel more or less intact. Therefore, new methods are also required. Indigenous-led health AI evaluation metrics must be built, extending beyond the standard technology-assessment toolkit into the cultural, spiritual, and relational dimensions of well-being that conventional rubrics do not measure [4, 7].

8.2 Phase 2: community validation

The next step is the community validation of the framework through sustained engagement with Truká and Fulni-ô knowledge holders, healers, youth, and community leadership. This study did not start from scratch. Under the Brazilian CONEP regulatory framework, Resolution CNS 466/2012, together with the specific provisions for research involving Indigenous peoples, no protocol involving the Truká or the Fulni-ô can be approved without prior documented consent from community leadership through community-controlled channels. The CONEP approval that already underpins the PAI INTEGRAL Project (parecer nº 5.927.482, issued March 7, 2023; CAAE 60271422.2.0000.8807) was therefore conditional on explicit Truká and Fulni-ô institutional support, consolidated through more than a decade of partnership, now entering a second analytical cycle. Phase 2 validation deepens the existing relationship around the specific question of digital health and AI governance, rather than opening engagement from scratch. This work will proceed in articulation with the Conselho Distrital de Saúde Indígena

(CONDISI) of DSEI Pernambuco, with the relevant lideranças and cacicado, and with the local Indigenous health teams (EMSIs). It will follow Free, Prior, and Informed Consent protocols established through community governance, and may result in substantial modification, reordering, or outright rejection of framework elements depending on community priorities. We explicitly commit to three things. Any such modifications will be incorporated into a follow-up publication co-authored by community members. The framework proposed here will not be advanced or implemented as a finished product without community approval. No Indigenous knowledge contributed during Phase 2 will become training data for AI without explicit, written, community-level consent under the terms of the ISE Code of Ethics, the CARE Principles, and the relevant CONEP-approved research protocol.

We make these commitments explicit in this section. If, during Phase 2, conducted in articulation with the Conselho Distrital de Saúde Indígena (CONDISI) of DSEI Pernambuco, with the relevant lideranças and cacicado of Truká and Fulni-ô territories, and with the local Indigenous health teams (EMSIs), Truká or Fulni-ô representatives propose substantial modifications, reordering, or partial rejection of the framework's domains, those changes will be incorporated into a follow-up publication co-authored with community members. The framework proposed in this manuscript will not be advanced or implemented as a finished product without community sign-off. The authors will also refrain from citing the present framework in policy or technology deployment contexts before community validation has taken place, except in scholarly discussions that openly mark its preliminary status. No Indigenous knowledge contributed during Phase 2 will be turned into training data for AI models without explicit, written, community-level consent under the terms of the ISE Code of Ethics, the CARE Principles, and the relevant CONEP-approved research protocol.

8.3 Longitudinal studies

Long-term studies are also required. The cultural continuity factors flagged as health-protective in the PAI cross-sectional studies [1] still have to be tested in longitudinal designs. Cohort studies that follow the Truká and Fulni-ô through phases of both technological integration and cultural change would show how digital health exposure interacts with traditional knowledge maintenance to shape health trajectories over time. The methodological requirements are demanding: sustained community partnership, stable funding, and governance structures that keep Indigenous authority over the direction of the research throughout. These conditions are rare in conventional academic research settings. They are non-negotiable for ethical, longitudinal engagement with Indigenous communities [2, 3].

9. Conclusion

The argument presented in this review is straightforward. Integrating digital health and artificial intelligence into Indigenous health systems presents both a significant opportunity and risk. The empirical anchor is the PAI Project. It shows three things. Cultural continuity acts as a cardiovascular protective factor for Fulni-ô [1]. Urbanization drives chronic kidney disease in Truká and Fulni-ô elders [2]. What occurs inside these communities is syndemic rather than reducible to discrete causes [3]. From these three findings, we draw a simple conclusion: any technology deployed here must address the relational, territorial, and epistemological dimensions of Indigenous well-being — not biomedical endpoints alone.

The international picture is uneven and inconsistent. Digital health work in Indigenous communities is mostly stuck in the pilot stage. AI applications are more discussed than evaluated. Governance frameworks are principled but rarely specific enough to work at the ethnomedicine–technology interface. Brazil offers both

institutional infrastructure (SUS, SasiSUS, SESAI) and a clear governance gap: no Indigenous-specific AI policy exists. The Ancestral–Digital Ethnomedicine Framework set out here — Territory before Data, Community before Platform, Care before Automation, Wisdom before Prediction, Reciprocity before Extraction, Cultural Continuity before Scalability, and Sustainable Health before AI — is one way to keep that gap from becoming the default. It still has to be validated by the communities themselves, tested in implementation, and adapted as it progresses. The framework is not complete. The point is the order of priority. Indigenous epistemological authority is prioritized. AI, scalability, and optimization come after, and on the terms the first sets [11, 33].

The move from ancestral knowledge to artificial intelligence is not a story of replacement, and ethnobiology has not told the story well until now. The ethnomedicine of the Truká and Fulni-ô has survived five centuries of upheaval. That experience teaches a point that is easy to lose in current AI debates: sustainable health futures will not be produced by technology alone. If they are produced at all, it will be through the careful embedding of digital tools inside communities, territories, ancestries, and reciprocal obligations that the tools themselves do not understand or comprehend. This review contributes to this re-weaving on three fronts. The first is empirical: the PAI Project provides evidence that cultural-ecological continuity functions as a determinant of Indigenous health in Northeast Brazil. The second is architectural: a domain-by-domain governance scheme (ADEF) for digital health and AI in Indigenous contexts. The third is practical: a working specification of what this means for SasiSUS, Brazilian AI legislation, and international Indigenous data sovereignty practice. The framework also bears the names of the community partners. The ethical weight of this naming is one of the reasons Phase 2 community validation is non-negotiable. In the work of re-weaving, ethnobiology and ethnomedicine are not folkloric appendices to the AI era. They are among the most useful teachers.

Positionality and reflexivity statement

The authorship of this manuscript brings together researchers who have worked with the Truká and Fulni-ô communities through the PAI Project over several years, alongside specialists in Indigenous health, ethnobiology, public health, digital health, and AI ethics. The lead author is a non-indigenous Brazilian researcher pursuing a doctorate in collective health with long-standing professional ties to members of the PAI Project consortium and community health workers and EMSI staff working in Truká and Fulni-ô territories. None of the authors of this initial publication are members of the Truká or Fulni-ô communities.

We acknowledge that engaging with Indigenous epistemologies from an academic perspective is necessarily contextual and partial. This review does not claim to represent Truká or Fulni-ô knowledge; rather, it seeks to learn from that knowledge, place it in dialogue with external literature, and propose a framework whose ultimate validity rests with the communities themselves. The empirical evidence we draw on derives from the PAI INTEGRAL Project, which operates under the formal endorsement of Truká and Fulni-ô community leadership — an endorsement that constituted a precondition for the CONEP approval (parecer nº 5.927.482) under which the research has been conducted, which has been renewed and consolidated over more than a decade of partnership, now entering a second analytical cycle. We commit to four things: We will disseminate this manuscript through PAI Project intermediaries, leaders, and community-validated channels before and after submission. We will produce a plain-language summary in Portuguese for community distribution purposes. We will initiate Phase 2 of this research programme with Truká and Fulni-ô co-authorship and governance under Free, Prior, and Informed Consent. We will not convert any Indigenous knowledge into raw materials for algorithmic exploitation. We accept the structural limits of a single-publication contribution at this stage and present this review as a step in a long-term, accountable relationship, rather than as a final statement.

List of abbreviations

Abbreviation	Full term
AAA	American Anthropological Association
ABRASCO	*Associação Brasileira de Saúde Coletiva* (Brazilian Association of Collective Health)
ADEF	Ancestral–Digital Ethnomedicine Framework
AI	Artificial Intelligence
AI/ML	Artificial Intelligence / Machine Learning
AMMO	AMMO Institute (institutional name)
APC	Article Processing Charge
BMC	BioMed Central
CAAE	*Certificado de Apresentação para Apreciação Ética* (Certificate of Ethical Submission and Appreciation)
CAPES	*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (Brazilian Federal Agency for Support and Evaluation of Graduate Education)
CARE	Collective Benefit, Authority to Control, Responsibility, and Ethics (Principles for Indigenous Data Governance)
CASAI	*Casa de Apoio à Saúde Indígena* (Indigenous Health Support House)
CC-BY	Creative Commons – Attribution license
CEP	*Comitê de Ética em Pesquisa* (Research Ethics Committee)
CKD	Chronic Kidney Disease
CNPq	*Conselho Nacional de Desenvolvimento Científico e Tecnológico* (National Council for Scientific and Technological Development)
CNS	*Conselho Nacional de Saúde* (Brazilian National Health Council)
CONEP	*Comissão Nacional de Ética em Pesquisa* (Brazilian National Research Ethics Commission)
CONSIDER	Strengthening Reporting of Health Research Involving Indigenous Peoples (reporting framework)
COVID-19	Coronavirus Disease 2019
CVD	Cardiovascular Disease
DOI	Digital Object Identifier
DSEI	*Distrito Sanitário Especial Indígena* (Special Indigenous Health District)
EBIA	*Estratégia Brasileira de Inteligência Artificial* (Brazilian National AI Strategy)
EBSERH	*Empresa Brasileira de Serviços Hospitalares* (Brazilian Hospital Services Company)
eHealth	Electronic Health
EHR	Electronic Health Records
EMSI	*Equipe Multidisciplinar de Saúde Indígena* (Multidisciplinary Indigenous Health Team)

ENTREQ	Enhancing Transparency in Reporting the Synthesis of Qualitative Research
FACEPE	*Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco* (Pernambuco State Foundation for Research Support)
FAIR	Findable, Accessible, Interoperable, Reusable (Principles for data management)
FNIGC	First Nations Information Governance Centre
FPIC	Free, Prior and Informed Consent
FUNAI	*Fundação Nacional dos Povos Indígenas* (Brazilian National Indigenous Peoples Foundation)
GIDA	Global Indigenous Data Alliance
HU-UNIVASF	*Hospital Universitário da Universidade Federal do Vale do São Francisco* (University Hospital of UNIVASF)
ICMJE	International Committee of Medical Journal Editors
ICT	Information and Communication Technology
ISE	International Society of Ethnobiology
JEE	Journal of Ethnobiology and Ethnomedicine
LILACS	*Literatura Latino-Americana e do Caribe em Ciências da Saúde* (Latin American and Caribbean Health Sciences Literature database)
LLM	Large Language Model
mHealth	Mobile Health
ML	Machine Learning
OCAP	Ownership, Control, Access, Possession (Principles for Indigenous data sovereignty)
ORCID	Open Researcher and Contributor Identifier
OSF	Open Science Framework
PAHO	Pan American Health Organization
PAI	*Projeto de Atenção à Saúde Integral Indígena* / Project of Accompaniment for Indigenous health
PNASPI	*Política Nacional de Atenção à Saúde dos Povos Indígenas* (Brazilian National Indigenous Health Policy)
PNPIC	*Política Nacional de Práticas Integrativas e Complementares* (Brazilian National Policy on Integrative and Complementary Practices)
PPGEcoH	*Programa de Pós-graduação em Ecologia Humana e Gestão Socioambiental* (Graduate Program in Human Ecology and Socio-environmental Management)
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
RNDS	*Rede Nacional de Dados em Saúde* (Brazilian National Health Data Network)
SasiSUS	*Subsistema de Atenção à Saúde Indígena* (Indigenous Health Sub-System of SUS)

SciELO	*Scientific Electronic Library Online*
SESAI	*Secretaria Especial de Saúde Indígena* (Special Secretariat of Indigenous Health)
SIASI	*Sistema de Informação da Atenção à Saúde Indígena* (Indigenous Health Information System)
SMS	Short Message Service
SUS	*Sistema Único de Saúde* (Brazilian Unified Health System)
TCLE	*Termo de Consentimento Livre e Esclarecido* (Free, Prior and Informed Written Consent form)
TEK	Traditional Ecological Knowledge
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
UNEB	*Universidade do Estado da Bahia* (State University of Bahia)
UNIVASF	*Universidade Federal do Vale do São Francisco* (Federal University of the São Francisco Valley)
UPE	*Universidade de Pernambuco* (University of Pernambuco)
WHO	World Health Organization

Declarations

Ethics approval and consent to participate

This review brings together the existing literature and does not involve primary data collection from human participants. The empirical findings that anchor the manuscript regionally come from the PAI Project — Projeto de Atenção à Saúde Indígena Integral no Vale do São Francisco — PAI INTEGRAL [1–3]. The PAI INTEGRAL project received approval from the Brazilian National Research Ethics Commission (CONEP) (parecer nº 5.927.482, CAAE 60271422.2.0000.8807, issued in Brasília on March 7, 2023). The proponent institution is the Fundação Universidade Federal do Vale do São Francisco (UNIVASF), with Anderson da Costa Armstrong as the principal investigator and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) as the primary funder. All primary PAI Project studies cited here were conducted under approval or prior related approvals from CONEP or local Research Ethics Committees (CEPs), with written informed consent (TCLE) from each participant, per Resolution 466/2012 of the Conselho Nacional de Saúde. Full ethics documentation is available in the original publications [1–3] and in the Plataforma Brasil registry under the cited CAAE number. The literature review and conceptual analysis presented here, conducted between June 2023 and January 2026, with drafting and revision running through May 2026, do not involve new primary data collection. The Ancestral–Digital Ethnomedicine Framework has not yet been validated by the communities; Phase 2 will pursue Free, Prior and Informed Consent (FPIC) from the governance bodies of the Truká and the Fulni-ô before any engagement begins, in line with the ISE Code of Ethics and the American Anthropological Association's ethical guidelines.

Authorization for publication

Not applicable. This manuscript does not contain individual participant data, identifiable images, or quoted speech that can be attributed to identifiable persons.

Accessibility of data and resources

This review used published literature obtained through systematic database search. The full search strategy, inclusion and exclusion criteria, conceptual coding sheet, and reference audit trail are provided in the Supplementary Files. The master table of all 285 identified records with relevance scoring is available from the corresponding author upon reasonable request, in accordance with the CARE Principles for Indigenous Data Governance.

All materials supporting the conclusions of this review — including the full search strategy with database queries and date windows, the inclusion and exclusion criteria, the relevance-scoring rubric, the PRISMA-ScR flow data, and the verified reference list with DOIs — are detailed within the manuscript itself. The methodological supplementary materials are available from the corresponding author upon reasonable request, in line with the CARE Principles for Indigenous Data Governance. The primary clinical-epidemiological data of the PAI INTEGRAL Project, including individual-level information on Truká and Fulni-ô participants, are not in any public repository. Access is restricted under CONEP approval no. 5.927.482 (CAAE 60271422.2.0000.8807) and the CARE Principles for Indigenous Data Governance. Researchers seeking access to PAI INTEGRAL primary data should contact the corresponding author and the PAI Project lead, who will route the request through the relevant institutional and community governance channels.

Conflicting interests

The authors declare no conflict of financial or non-financial interests.

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Authors' contributions

The manuscript was produced through the collaborative authorship framework of the PAI consortium (Projeto de Atenção à Saúde Integral Indígena / Project of Accompaniment for Indigenous Health) together with the Programa de Pós-graduação em Ecologia Humana e Gestão Socioambiental (PPGEcoH) at UNEB, the AMMO Institute, the Hospital Universitário da UNIVASF, UNIVASF, and UPE. All authors met the four ICMJE authorship criteria: substantial contribution to the work, drafting or critical revision of important intellectual content, final approval of the published version, and accountability for all aspects of the study.

AM (Américo Mota) conceived the review, designed the search strategy and conceptual coding framework, developed the original Ancestral–Digital Ethnomedicine Framework, wrote the manuscript, and led the writing process. AM is the corresponding author of this editorial correspondence.

BFA (Bruna Felix de Almeida) participated in the literature review, screening, and conceptual coding, co-wrote the Methods section, and provided the manuscript with a close review focused on cultural safety protocols and

CONSIDER reporting.

IDSLB (Isabella Diniz de Souza Lins Bunge) assisted with literature screening, synthesized material on intermediality among the Truká and the Fulni-ô, and critically revised the sections on ethnomedicine and Brazilian Indigenous health policy.

JMN (Jandir Mendonça Nicacio) contributed empirical expertise on arboviral exposure and cardiac biomarkers from the PAI Project, provided the primary clinical-epidemiological analysis for §2.4, and reviewed the manuscript carefully for the accuracy of clinical and public-health content.

VCP (Vanessa Cardoso Pereira) has expertise in respiratory and oral health from the PAI Project, helped integrate intermedical and biomedical pathways in §§5 and 6, and provided critical revision of the manuscript.

TACdC (Thiago Augusto Cavalcante de Carvalho) contributed to the qualitative thematic synthesis and application of ENTREQ, supported the ethnomedicine sections and the framework's domains "Wisdom before Prediction" and "Cultural Continuity before Scalability," and critically reviewed the manuscript.

PAM (Paula Andreatta Maduro) contributed expertise on physical activity and cardiometabolic determinants, substantiated the link between sedentarism, urbanization, and cardiovascular outcomes as documented by PAI, helped shape the community-based health-promotion framing, and critically reviewed the manuscript.

PAS (Paulo Adriano Schwingel) brought biostatistical and public-health methodological expertise to the design of the review and to the rigour of the literature mapping (PRISMA-ScR/ENTREQ), critically evaluated the framework for empirical testability, and revised the manuscript thoroughly.

CDFdS (Carlos Dornels Freire de Souza) contributed epidemiological expertise on urbanization gradients and Indigenous health transitions, interpreted §§2.2 and 2.3 (Armstrong et al. 2023; Gomes et al. 2023), and critically revised the manuscript.

OVG (Orlando Vieira Gomes) brought clinical expertise on chronic kidney disease in older Indigenous adults, contributed the empirical analysis for §2.3, endorsed the clinical implications of the framework (particularly "Wisdom before Prediction" and "Care before Automation"), and critically revised the manuscript.

AdCA (Anderson da Costa Armstrong), senior author and lead of the PAI Project, set the empirical foundation of the review on PAI evidence, oversaw the integration of clinical-epidemiological and ethnomedical perspectives, provided overall scientific guidance, and revised the manuscript carefully for important intellectual content.

All authors reviewed and approved the final manuscript and accepted responsibility for all aspects of the work, ensuring that any questions about the accuracy or integrity of any part of it have been properly investigated and resolved.

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Use of AI for language editing

The authors are native Portuguese speakers and used AI-based assistance only for grammatical, orthographic, and stylistic editing of the English-language manuscript that they had written themselves.

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Tables

Table 1. Funnel of evidence by geographic and conceptual scale

Scale	Key knowledge systems and frameworks	Health issues highlighted	Digital health / AI evidence	Ethical implications	Key references
Global / Indigenous worldwide	Ethnomedicine; TEK; CARE Principles; OCAP; Two-Eyed Seeing; cognitive sovereignty; UNDRIP; ISE Code of Ethics	Disparities across CVD, diabetes, CKD, mental health, infectious disease	Telehealth, mHealth, EHR; aspirational AI frameworks; emerging cognitive-sovereignty literature	Risks of digital colonialism, data extractivism, algorithmic bias; need for FPIC and Indigenous data sovereignty	[4–11,14,15,25,26]
Americas	Pan-Indigenous health movements; FNIGC; Pan American Health Organization initiatives	Cardiovascular and metabolic disease transitions; mental health; infectious disease	Pilot digital health programmes; AI imaging in remote settings	Need for hemispheric Indigenous AI governance; mistrust based on extractive research history	[4,14,20,21,22]
Brazil	SUS, SasiSUS, SESAI, DSEI; PNASPI; PNPIC	Indigenous health inequities; integration of traditional medicine	Estratégia de Saúde Digital; RNDS; PL 2338/2023 (AI bill); EndoConnect implementation	SasiSUS underfunded; absent Indigenous-specific AI governance; SIASI excludes ethnomedical categories	[12,13,19,24,27]
Northeast Brazil	Sertão semi-arid Indigenous knowledge; intermedicalidade; documented Caatinga medicinal taxa (Anacardium occidentale, Spondias tuberosa, Myracrodruon urundeuva, Schinopsis brasiliensis, Anadenanthera colubrina, Caesalpinia pyramidalis); women healers	CVD, CKD, arboviral exposure; documented Truka-Fulni-o differential in hypertension prevalence interpreted as composite effect of urbanisation gradient and culturally-structured ecological conditions	Tele-ultrasound; PAI tele-imaging; limited connectivity	DSEI Pernambuco implementation gaps; need for cultural calibration	[1–3,12,13,19,24]
Pernambuco / Truká / Fulni-ô	Toré; Yathê; Ouricuri (restricted); rezas; ethnobotany	Hypertension differential (Truká vs. Fulni-ô); CKD in elders; arboviral exposure	PAI Project tele-ultrasound deployment; community-based education	Cultural-safety protocol on restricted knowledge; need for community validation of any digital tool	[1–3,12,13,29–31]

Table 2. PAI Project and Northeast Brazil evidence base

Study / source	Indigenous group	Health domain	Relevance to ethnomedicine / human ecology	Relevance to digital health / AI futures	Claim level
Armstrong et al. 2023 [1]	Truká; Fulni-ô; urban controls	Hypertension; cardiovascular risk	Cultural continuity as health-protective factor; differential urbanisation	Direct evidence that cultural continuity must be preserved by, not displaced by, digital health	1
Gomes et al. 2023 [2]	Truká; Fulni-ô (older adults)	Chronic kidney disease	Body composition, diet, physical activity differ from urban reference	Algorithms calibrated for non-Indigenous populations risk systematic misclassification	1
Nicacio et al. 2024 [3]	Fulni-ô	Arboviral exposure; cardiac biomarkers	Syndemic ecology of semi-arid; vector breeding tied to drought adaptation	AI syndemic models must reflect local ecological texture; not extrapolated from urban atlases	1
Vieira et al. 2013 [12]	Truká	Intermedicalidade	Coexistence of biomedical and traditional systems; rezas, Toré, herbal practice	Telehealth and AI must accommodate plural therapeutic pathways	2
Alves et al. 2011 [13]	Fulni-ô	Traditional medicine and education	Yathê as vehicle of transmission; community-led pedagogy	Digital tools must be linguistically and culturally specific; Ouricuri remains protected	2
Santos et al. 2016 [19]	Semi-arid Indigenous (multiple)	Zootherapy and migration	Ethnobiological knowledge is mobile and adaptive	Digital documentation must respect community authority over knowledge mobility	2
Lima and Nunes 2025 [24]	Kantaruré (neighbouring)	Women's medicinal-plant knowledge	Gendered ethnomedical knowledge; conservation-health link	Digital tools should support, not replace, intergenerational transmission	2

Table 3. The Ancestral–Digital Ethnomedicine Framework: seven domains

Domain	Indigenous principle	Digital health counterpart	Risk of disembedded AI	Integration pathway	Claim level
1. Territory before Data	Health inseparable from land, river, sacred sites	Geospatial health data; environmental monitoring	Sacred landscapes reduced to data layers; sensitive territorial information exposed	Indigenous spatial knowledge as primary data layer; community-controlled access; FPIC required	3
2. Community before Platform	Collective health decisions in kinship and ceremony	Individual user accounts; one-to-one telemedicine	Fragmentation of collective practice; algorithmic recommendations displace council	Family/community access models; community councils retain authority over platform adoption	3
3. Care before Automation	Healing as relational presence	AI chatbots; automated triage	Stripping of relational therapeutic dimension	AI as support tool for human healers (traditional and biomedical), never replacement	3
4. Wisdom before Prediction	Wisdom as contextual, accumulated understanding	Predictive analytics; risk stratification	Devaluation of Indigenous observational knowledge; pathologisation of adaptive practices	Traditional indicators as validated inputs; algorithmic outputs interpreted by knowledge holders	3
5. Reciprocity before Extraction	Relationships governed by giving back	Health data collection; biobanking	Extractive data pipelines fuel external value	Mandatory benefit-sharing; community partial/full ownership of derived models	3
6. Cultural Continuity before Scalability	Cultural practices as health determinants	Standardised, scalable platforms	“Culturally neutral” design erases specificity	Community-specific design; multilingual interfaces (e.g., Yathê when consented); local governance	3
7. Sustainable Health before AI	Health sustainability across generations	AI-driven optimisation; technology-dependent care	Dependence on connectivity, vendors, infrastructure	AI as supplement, never substitute; communities retain non-digital capacity; exit protocols	4

Figures

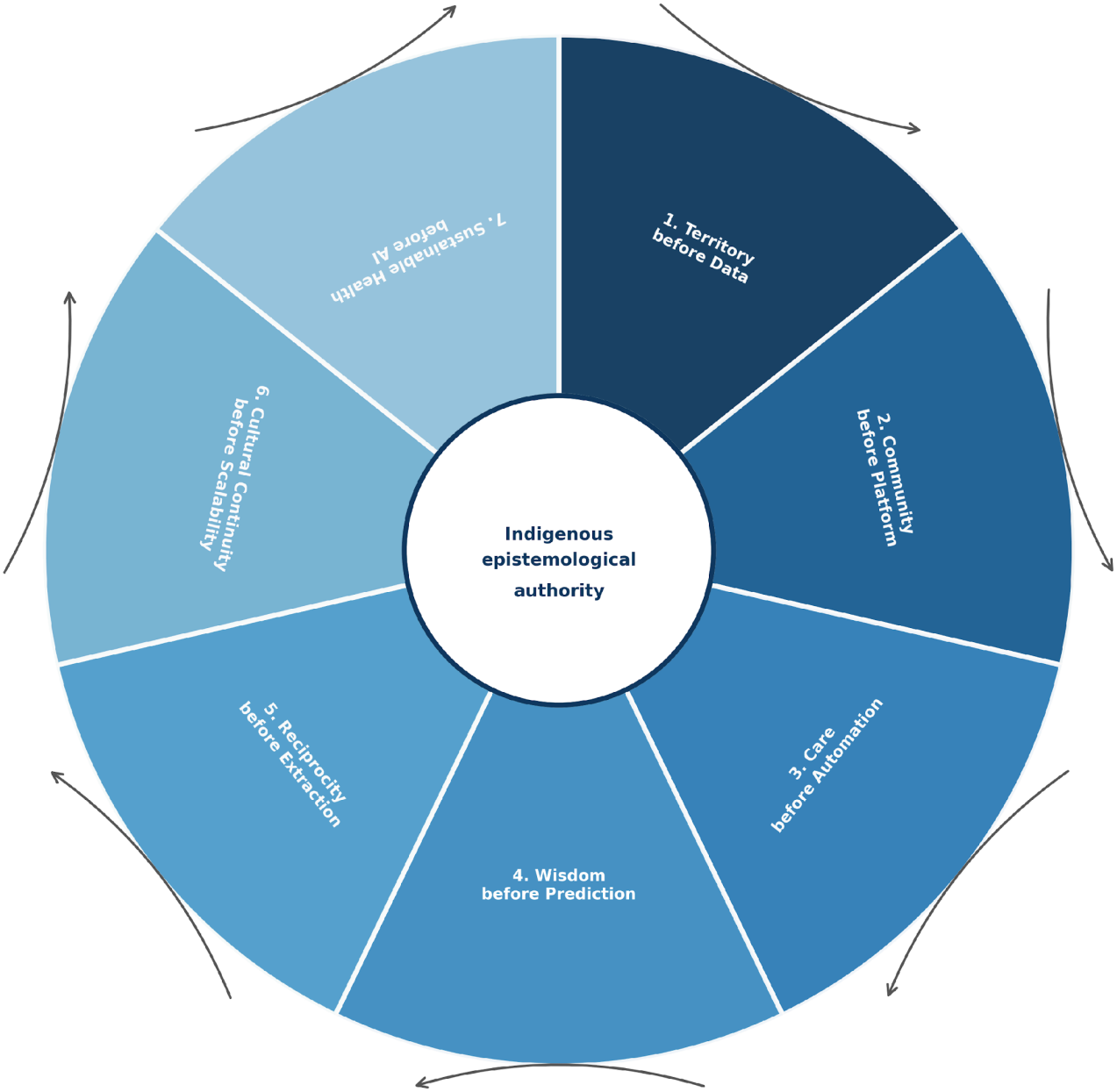


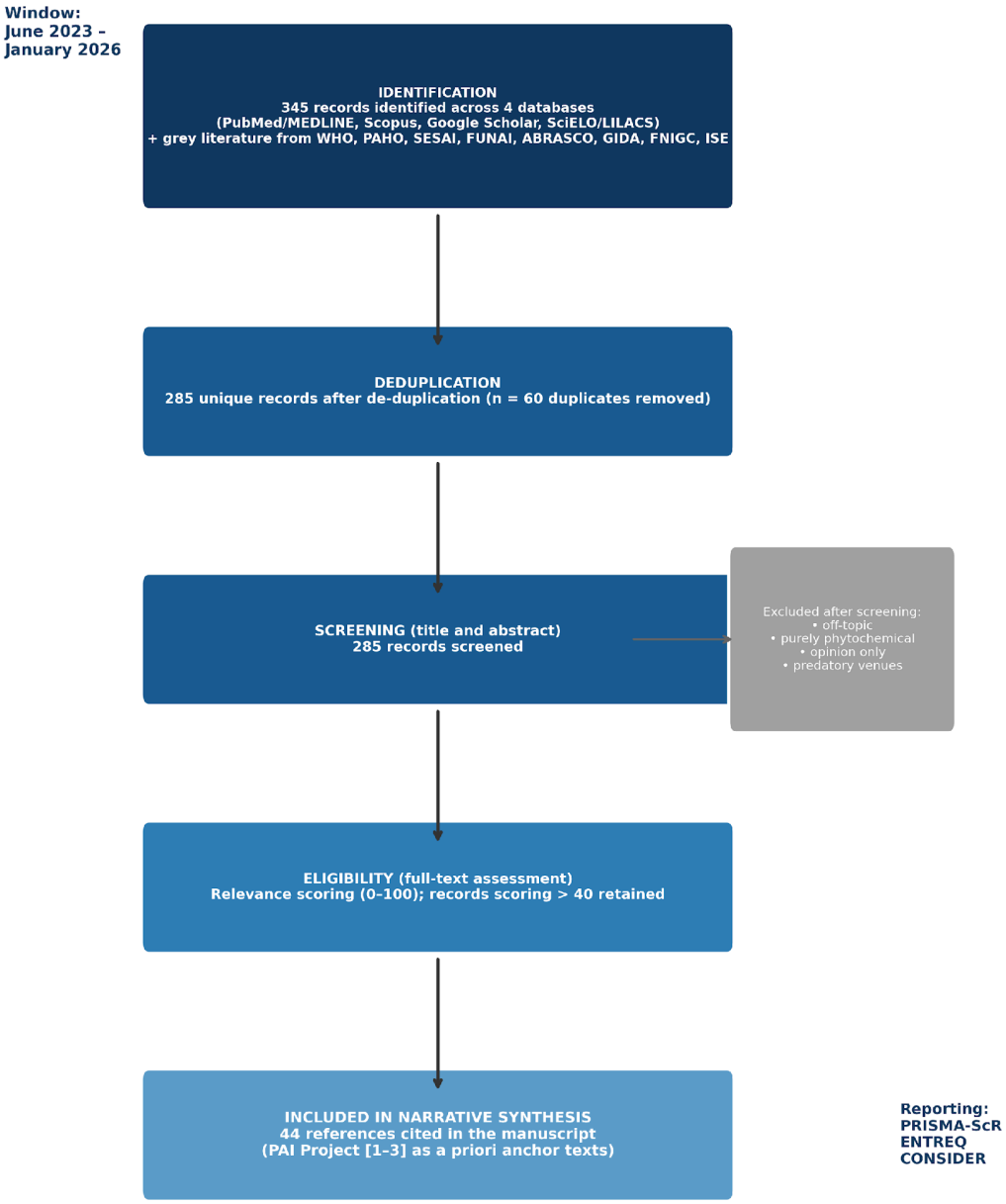
Figure 2. The Ancestral–Digital Ethnomedicine Framework (ADEF): circular model of seven interdependent domains.

Figure 1

The Ancestral–Digital Ethnomedicine Framework (ADEF): circular model

A circular diagram with seven equal sectors, each representing one of the framework's domains (Territory before Data, Community before Platform, Care before Automation, Wisdom before Prediction, Reciprocity before Extraction, Cultural Continuity before Scalability, and Sustainable Health before AI). The centre of the circle is labelled “Indigenous epistemological authority.” The arrows around the perimeter indicate non-hierarchical,

mutually reinforcing relationships among the domains. A color-blind-safe sequential palette was used, the typography was sans-serif, and the line weights were kept uniform throughout.



Supplementary Figure 1. PRISMA-ScR flow diagram.

Figure 2

PRISMA-ScR flow diagram

Standard PRISMA-ScR flow diagram summarizing identification (n = 345 records across PubMed/MEDLINE, Scopus, Google Scholar, and SciELO/LILACS, plus grey literature), de-duplication (n = 285 unique records; n = 60 duplicates removed), title/abstract screening, full-text eligibility assessment with relevance scoring (0–100; records scoring > 40 retained), and inclusion in the narrative synthesis (32 references cited in the manuscript, with the three principal PAI Project publications [1–3] identified a priori as anchor texts). The reasons for exclusion were tallied (off-topic, non-Indigenous focus, purely phytochemical, opinion without scholarly grounding, predatory or unverifiable, and duplicates). The review window (June 2023 – January 2026) and the joint application of the PRISMA-ScR, ENTREQ, and CONSIDER reporting frameworks are annotated.