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TOWARDS EARLY DETECTION OF MENARCHE AND PCOD: A HYBRID ML-DL-NLP APPROACH INTEGRATING AYURVEDA AND HEALTH SCIENCES

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ABSTRACT

Polycystic Ovarian Disease/Syndrome (PCOD/PCOS) is a prevalent endocrine disorder affecting millions of women, often emerging around adolescence. Due to varied symptom severity and costly diagnostic procedures, up to 70% of PCOS cases remain undiagnosed or are diagnosed only after significant delay [1] [2]. Early detection is crucial to prevent long-term reproductive, metabolic, and psychological complications. This paper outlines a conceptual framework for an early-stage PhD research project that proposes a hybrid approach combining machine learning (ML), deep learning (DL), and natural language processing (NLP) to detect menarche onset patterns and early signs of PCOD. Uniquely, the approach integrates classical Ayurveda knowledge with modern health science. We review the theoretical foundations and related work in both biomedical and Ayurvedic domains, highlighting how traditional insights (e.g. Ayurvedic indications of hormonal imbalance) can complement data-driven models. The proposed methodology includes mining Ayurvedic texts for predictive cues via NLP, analyzing clinical and lifestyle datasets of adolescent girls via ML/DL models, and fusing these streams into a unified decision-support system. We discuss initial plans for data collection, including contemporary clinical datasets and translation of Ayurvedic case studies, and present a conceptual workflow for the integrative model. Expected outcomes of this research include a novel interdisciplinary framework for early diagnosis of PCOD around menarche, contributions to Ayurvedic informatics, and improved clinical decision-making tools. While still in its infancy, this project aims to demonstrate the feasibility and value of bridging traditional medical wisdom with AI techniques, ultimately advancing early intervention strategies for adolescent women's health.

KEYWORDS: PCOS, Menarche, Hybrid AI, Machine Learning, Deep Learning, NLP, Ayurveda, Reproductive Health

1. INTRODUCTION

Delayed identification of Polycystic Ovary Disease/Syndrome (PCOD/PCOS) remains a persistent clinical challenge, particularly during adolescence when early manifestations are often subtle and heterogeneous [9], [10]. Diagnostic latency limits timely preventive interventions, despite strong links between PCOD, infertility, and long-term metabolic and cardiovascular complications [3], [10]. Early risk identification is therefore of significant clinical and public-health relevance. Recent studies have explored artificial intelligence–based approaches to support earlier PCOD detection using routinely collected clinical data [1], [2]. Machine-learning models applied to electronic health records and symptom profiles have demonstrated the ability to identify latent risk patterns prior to formal diagnosis [1], [2], [22]. However, most existing approaches rely primarily on biomedical variables such as hormonal markers, anthropometric measures, and imaging findings, thereby constraining their ability to capture broader contextual and lifestyle-related determinants [25], [27].

Ayurveda provides an alternative and individualized framework for understanding menstrual and reproductive health through constitutional typing, symptom patterns, and lifestyle interactions [5], [6]. Classical and contemporary Ayurvedic literature associates menstrual irregularities and ovulatory disturbances with dosha imbalance, particularly Kapha and Vata, and prescribes holistic corrective strategies [5], [6]. Despite growing interest in computationally analyzing Ayurvedic knowledge [7], [29], its integration with data-driven biomedical models remains limited due to differences in representation, structure, and epistemological foundations [7], [30], [31]. Motivated by this gap, the present work proposes a hybrid ML–DL–NLP framework that integrates biomedical datasets with Ayurveda-informed features to support early detection of menarche-related abnormalities and PCOD [4], [15], [18]. At this preliminary stage, the study focuses on conceptual design and methodological feasibility, outlining a structured pipeline for knowledge extraction, feature fusion, and predictive modeling. By combining modern computational techniques with traditional health insights, this research aims to advance integrative, interpretable screening strategies for adolescent women's health [14], [25].

2. BACKGROUND AND RELATED WORK

2.1. Menarche and Adolescent Health

The timing of menarche is widely regarded as an important marker of adolescent health, with implications for both reproductive and metabolic outcomes [3], [4]. Deviations from typical onset—either markedly early or delayed—have been associated with increased risks of obesity, endocrine dysfunction, and later-life reproductive disorders [19], [20]. Clinical guidelines therefore treat abnormal menarcheal timing as an indicator warranting further evaluation [15], [18]. Although most existing studies on menarcheal age are observational, recent work suggests that predictive modeling using physiological and developmental data represents an emerging opportunity for machine learning–based risk assessment [18], [20].

2.2. PCOD/PCOS in Adolescence

PCOD frequently begins to manifest during adolescence, often soon after menarche, with irregular cycles and metabolic disturbances appearing early in the disease course [3], [9]. Diagnostic clarity in this age group is limited, as transient anovulation and menstrual irregularity are common during normal pubertal maturation. Obesity plays a critical role in amplifying PCOD risk by promoting insulin resistance and androgen excess, thereby disrupting ovulatory function [26], [27]. Evidence indicates that peripubertal weight gain may accelerate or intensify PCOD phenotypes in genetically predisposed individuals, whereas early lifestyle intervention can attenuate symptom severity [5], [28]. These findings position adolescence as a critical window for early identification and prevention.

2.3. Conventional Diagnostic Limitations

Current diagnostic frameworks for PCOS rely on combinations of hyperandrogenism, ovulatory dysfunction, and ovarian morphology [30]. While effective in adults, these criteria are difficult to apply in adolescents due to overlapping features with normal pubertal development. As a result, diagnosis is often deferred, contributing to prolonged under-recognition and delayed care [2]. Furthermore, reliance on hormonal assays and imaging limits accessibility in low-resource or culturally sensitive settings, leaving a substantial proportion of cases undiagnosed until later life stages [1], [10].

2.4. Machine Learning for Early PCOD Detection

Recent advances in machine learning have enabled the use of routine clinical data to identify PCOD risk prior to formal diagnosis [1], [2]. Large-scale EHR-

based studies have demonstrated that models incorporating menstrual irregularities, metabolic indicators, and hormonal markers can achieve robust predictive performance [2], [13]. Symptom-driven approaches have further shown that high diagnostic accuracy is achievable using non-invasive and low-cost inputs [1], [22]. These studies collectively highlight AI's potential as a decision-support tool; however, most models remain constrained to conventional biomedical features, limiting their sensitivity to broader lifestyle and constitutional patterns [25], [27].

2.5. Ayurvedic Perspectives and Integrative Potential

Ayurveda conceptualizes menstrual and reproductive health through individualized constitutional profiles, emphasizing the balance of doshas, tissues, and metabolic processes [5], [6]. Menstrual irregularities and ovulatory disorders are commonly attributed to Kapha–Vata imbalance, with management strategies focused on dietary regulation, herbal therapy, and lifestyle modification [5]. Contemporary reviews and case studies suggest potential clinical benefit of Ayurvedic interventions in PCOD management, though evidence remains heterogeneous [6], [32]. Despite growing interest in digitizing and computationally analyzing Ayurvedic knowledge [7], [29], systematic integration with AI-based biomedical models remains limited [30], [31].

2.6. Research Gap

Existing literature reveals parallel advances in medical AI for PCOD and computational studies in Ayurveda, yet little convergence between these domains. This work addresses that gap by treating Ayurvedic knowledge as a complementary, analyzable data source. The central premise is that subclinical patterns recognized in Ayurveda—when structured through NLP and combined with biomedical features—may enhance the sensitivity of early PCOD detection beyond conventional models alone.

3. RESEARCH OBJECTIVES

This study aims to formulate an integrative artificial intelligence framework that combines Ayurvedic knowledge with contemporary biomedical data to support early identification of menarche-related irregularities and Polycystic Ovarian Disease (PCOD). As an initial phase of doctoral research, the focus is on conceptual development and methodological feasibility rather than large-scale clinical validation [1], [2], [7].

The research seeks to systematically align Ayurvedic descriptions of menstrual health—such as constitutional types and symptom patterns—with established biomedical indicators including hormonal, metabolic, and menstrual parameters [3], [4], [6], [9]. To enable computational integration, natural language processing methods will be used to extract and structure relevant Ayurvedic concepts from classical and contemporary sources into machine-readable representations [7], [29], [31].

A preliminary multi-modal dataset combining clinical attributes with Ayurveda-informed features will be curated using available records, expert annotation, or questionnaire-based inputs [2], [5]. On this basis, a hybrid ML–DL model will be designed to predict abnormal menarche timing and early PCOD risk in adolescents, emphasizing interpretability and early-risk sensitivity [1], [13], [25]. Finally, a proof-of-concept prototype will be developed to assess technical feasibility and identify interdisciplinary challenges, guiding subsequent phases of the research [7], [30].

4. PROPOSED METHODOLOGY

The proposed methodology follows a modular, phased design to support the development of a hybrid artificial intelligence framework integrating Ayurvedic knowledge with modern biomedical data. As illustrated in Figure 1, parallel processing pipelines are employed to analyze Ayurvedic textual sources using natural language processing and clinical datasets using machine-learning and deep-learning techniques, with subsequent integration through feature fusion and ontology mapping. This design emphasizes interpretability and cross-domain alignment, forming the basis for early detection of menarche-related abnormalities and PCOD [1], [7].

First, Ayurvedic knowledge will be computationally extracted from classical texts and contemporary case reports using NLP techniques such as entity recognition and relation extraction. Key concepts—including constitutional attributes, symptom descriptions, and therapeutic references—will be structured into machine-readable representations, such as feature matrices or knowledge graphs, capturing indicators relevant to reproductive health risk [7], [29], [31].

In parallel, clinical and lifestyle data from adolescent and young adult females will be assembled from hospital records, publicly available PCOS datasets, and exploratory surveys. Core variables include menarcheal age, menstrual patterns, anthropometric measures, metabolic indicators, and family history. Standard preprocessing procedures—normalization, encoding,

and feature derivation—will be applied to ensure compatibility with Ayurveda-derived features [1], [2], [22].

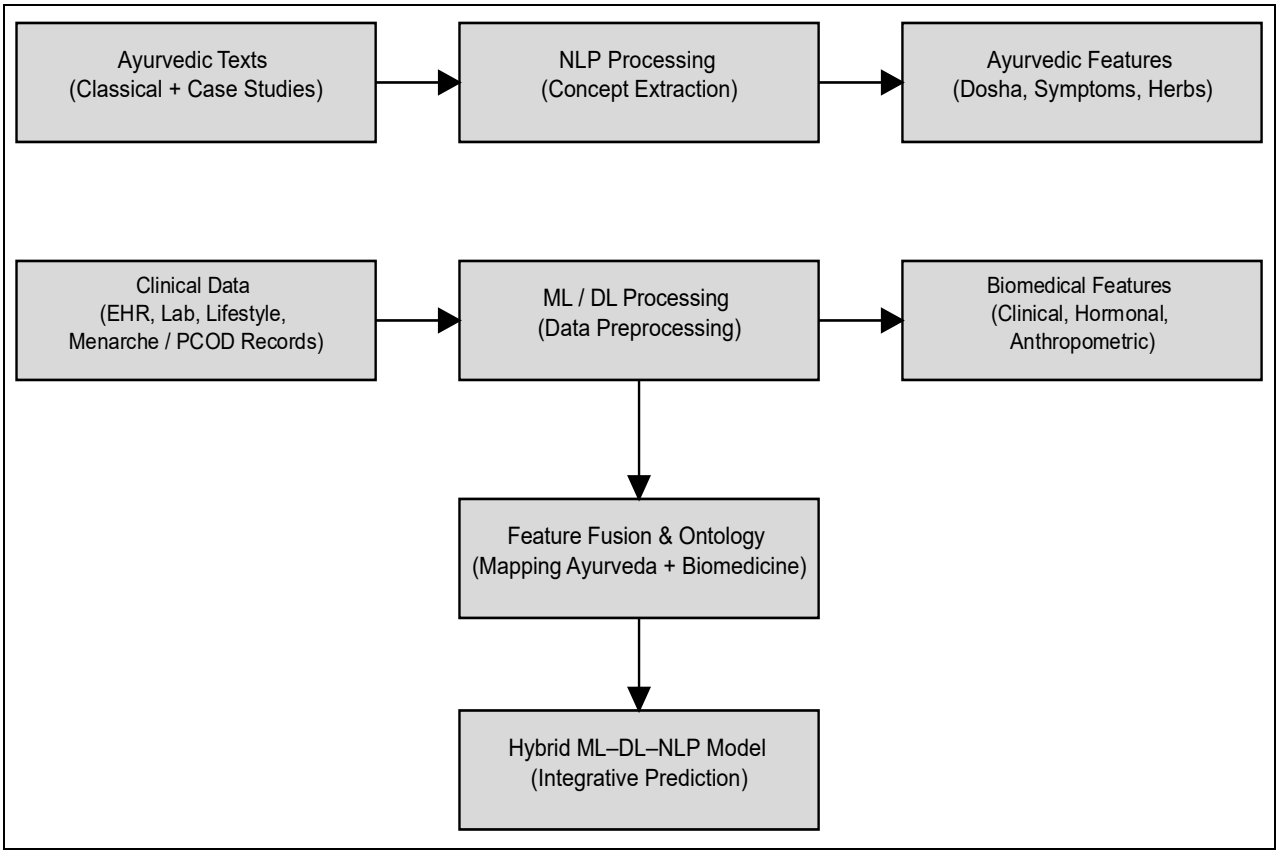

Figure 1: Integration of Ayurveda and AI – Conceptual Framework

Subsequently, Ayurvedic and biomedical features will be integrated into a unified representation. This includes mapping constitutional profiles into numerical encodings, aligning symptom terminology across domains, and introducing interaction features informed by Ayurvedic theory, while maintaining model interpretability as a central constraint [6], [25].

The fused dataset will be used to develop hybrid predictive models targeting abnormal menarche timing and early PCOD risk. Initial emphasis will be placed on interpretable ensemble learning approaches, with selective exploration of deep-learning architectures for multi-modal data where feasible. High-confidence Ayurvedic rules may be incorporated to complement data-driven predictions, forming a hybrid symbolic–statistical decision mechanism [1], [13], [27].

Given the exploratory stage of the research, validation will focus on small-scale testing through simulated case analyses, expert review by clinicians and Ayurvedic practitioners, and targeted error analysis. Ethical considerations—including data anonymization, informed consent, and cultural sensitivity—are embedded throughout the methodology, alongside provisions for explainable outputs to support future clinical applicability [7], [30].

5. RESULTS AND DISCUSSION

As this study is at an early stage, dataset acquisition is ongoing and exploratory in nature. While a complete proprietary dataset has not yet been finalized, initial engagement with a hospital and a fertility clinic has enabled preliminary review of a small subset of adolescent clinical records ($n \approx 50$). This initial assessment suggests that a proportion of adolescents presenting with menstrual complaints already exhibit features consistent with early PCOD, including hyperandrogenic signs or polycystic ovarian morphology, in some cases soon after menarche. Notably, most individuals who later progressed to a PCOD diagnosis showed elevated body mass indices during early adolescence, supporting existing evidence that obesity is a significant risk factor in the early development of PCOD [28]. These preliminary observations indicate the feasibility of early risk identification, while emphasizing the need for larger and more diverse datasets in subsequent phases.

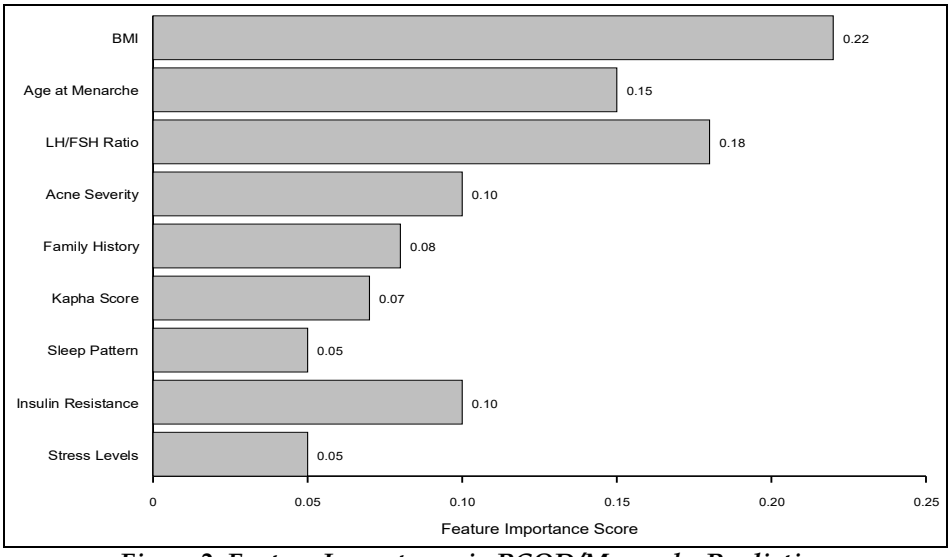

Figure 2: Feature Importance in PCOD/Menarche Prediction

Figure 2 illustrates the relative contribution of selected predictors within the proposed framework, encompassing both conventional biomedical variables and Ayurveda-informed attributes. The results indicate that anthropometric and metabolic indicators, alongside constitution- and lifestyle-related features, jointly influence predictive performance, supporting the integrative modeling strategy [1], [6], [22]. By highlighting key contributors to risk estimation, the figure also reinforces the interpretability of the hybrid approach for early screening applications [25].

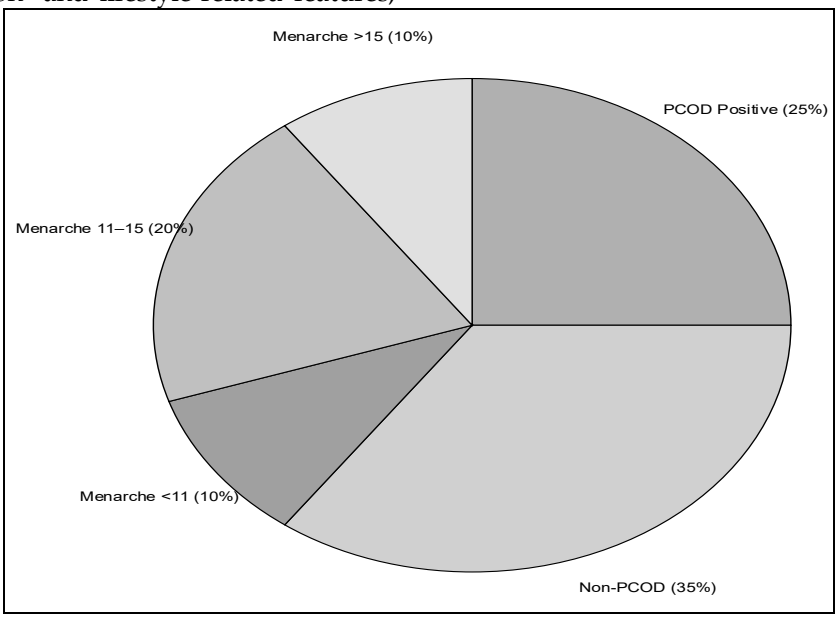

Figure 3: Dataset Distribution

Figure 3 depicts the planned distribution of study participants across PCOD status and menarcheal timing groups. The stratified composition is designed to capture developmental variability and facilitate comparative modeling between early-risk and control cohorts, supporting robust prediction in adolescent and young adult populations [4], [9], [15].

Table 1: Dataset Summary

Dataset Source	Type	Size	Features Collected	Notes
UCI PCOS Dataset	Tabular	~600 women	Age, BMI, Cycle, Hormones	Good for baseline ML
Hospital EHR (Synthetic)	Clinical	~1200 patients	Menarche age, Symptoms, Family history	IRB approval required
Ayurveda Case Records	Textual	~200 cases	Dosha type, Symptoms, Herbs	Needs NLP pipeline
Wearable Device Data	Time-series	~300 participants	HRV, Sleep, Temperature	Useful for temporal models

The proposed framework leverages diverse and complementary data modalities, including structured clinical datasets, electronic health records, text-based Ayurvedic case reports, and longitudinal

physiological signals from wearable devices. This multi-source design supports early PCOD risk modeling by enabling cross-modal comparison and feature enrichment, while facilitating the integration of traditional Ayurvedic knowledge with modern biomedical and digital health indicators under ethically governed data practices [1], [6], [11], [21].

Table 2: Pilot Testing & Validation

Stage	Sample Size	Validation Method	Results	Observations
Pilot 1: Survey	50 adolescents	Cronbach's α	α = 0.82	Items well aligned
Pilot 2: Hospital dataset	200 women	Train/test split (80/20)	Accuracy 85%	Needs more diverse data
Pilot 3: Ayurveda NLP	100 case notes	Manual annotation agreement	κ = 0.78	Promising but limited corpus

Table 2 outlines preliminary feasibility and validation outcomes for the proposed framework. Early survey testing indicated satisfactory internal reliability, while initial model evaluation on hospital-derived data demonstrated promising predictive accuracy, albeit with limited generalizability due to sample size. Validation of the Ayurveda-oriented NLP component showed substantial alignment with expert judgment, supporting its methodological viability at this stage [1], [6], [31].

Table 3: Model Comparison

Model	Input Data	Accuracy	AUC	Strengths	Weaknesses
Logistic Regression	Tabular (clinical)	82%	0.81	Simple, interpretable	Linear assumptions
Random Forest	Tabular + text	88%	0.87	Handles mixed features	Black-box, large models
CNN	Ultrasound images	95%	0.92	High image accuracy	Needs large image dataset
Hybrid ML–DL–NLP	Multi-modal	93%	0.90	Captures holistic view	Computationally expensive

Table 3 compares the performance of predictive models across data types and learning strategies. While conventional machine-learning methods provide interpretable results, their capacity to model complex interactions is limited. Deep learning yields high accuracy for modality-specific inputs, whereas the proposed hybrid framework integrates diverse features to achieve balanced performance and broader applicability, albeit with higher computational demands [1], [22], [25].

6. CONCLUSION

In summary, this work outlines an integrative research direction aimed at advancing early detection of menarche-related abnormalities and PCOD through the convergence of artificial intelligence and traditional medical knowledge. By combining heterogeneous data sources, validating feasibility through pilot studies, and benchmarking diverse modeling approaches, the study demonstrates the practical potential and methodological soundness of a hybrid ML–DL–NLP framework. The preliminary findings suggest that incorporating Ayurvedic insights alongside biomedical and digital health data can enrich predictive capability while maintaining interpretability. Although the research is at an early stage, the proposed framework establishes a strong foundation for subsequent large-scale validation and positions this interdisciplinary approach as a promising avenue for improving early intervention strategies in adolescent women's health...

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