Advancing Endometrial Cancer Prediction with Artificial Intelligence: A Study on Women's Risk Stratification

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Abstract

Endometrial cancer is the sixth most common cancer in women globally, necessitating improved predictive tools. This study evaluates artificial intelligence (AI) models for enhancing risk stratification in pre- and postmenopausal women. This retrospective cohort study was conducted at Saveetha Medical College and Hospital between January 2019 and May 2024, including 227 consecutive female patients aged ≥30 years with symptoms warranting endometrial evaluation. Patients were randomly divided into training and validation sets (80:20). Three AI models—Random Forest (RF), Logistic Regression (LR), and Multilayer Perceptron (MLP)—were developed using Python with feature selection via the Boruta algorithm. Model performance was assessed through 5-fold cross-validation and ROC curve analysis. Heavy menstrual bleeding was the predominant symptom (98.7%), with endometrial thickness ranging from 3-22mm. Nearly half (49.3%) presented with comorbidities. Kruskal-Wallis testing showed no significant relationship between symptom duration and endometrial thickness ($\chi^2(13)=8.971$, $p=0.775$). Among AI models, Logistic Regression demonstrated superior predictive capability (AUC=0.82), followed by Multilayer Perceptron (AUC=0.79) and Random Forest (AUC=0.76). This study demonstrates the potential of AI-based models to improve endometrial cancer risk stratification by integrating multiple clinical parameters. Multi-parameter AI models offer superior predictive accuracy compared to conventional clinical metrics alone, supporting their implementation in personalized patient care.

Keywords: Artificial intelligence, Diagnostic algorithm, Endometrial cancer, Machine learning, Risk stratification, Women's health

Introduction

Endometrial cancer is a significant health concern, particularly among women in both premenopausal and postmenopausal stages. According to the World Health Organization (WHO), endometrial cancer is the sixth most common cancer in women globally, with over

380,000 new cases diagnosed each year.[1] The increasing prevalence of this cancer underscores the urgent need for effective predictive tools that can aid in early diagnosis and improve treatment outcomes. Traditional diagnostic methods, while valuable, are often limited by human error and the complexity of interpreting medical data, particularly in general clinical practice and rural settings.

In recent years, advancements in digital healthcare technologies, such as artificial intelligence (AI), have revolutionized the medical field, offering promising new avenues for enhancing diagnostic accuracy and patient care. AI methodologies, including machine learning (ML), deep learning (DL), and natural language processing (NLP), have demonstrated remarkable potential in improving clinical systems, managing patient records, and treating various diseases.[2] Specifically, AI techniques such as convolutional neural networks, knowledge graphs, and transformers have emerged as powerful tools in the diagnosis and treatment of a range of medical conditions, including endometrial cancer. The integration of AI into the diagnostic process has enabled medical professionals to achieve higher levels of diagnostic accuracy and efficiency, thus advancing the quality of healthcare services provided to patients.

Despite these technological advancements, significant challenges remain in the operational implementation of AI within healthcare systems. One of the primary challenges is the need for AI algorithms to be trained on data that accurately represents diverse populations to ensure their applicability in real-world clinical settings. Current trends, such as the exponential growth of electronic health records and the proliferation of user-generated data, have created a data-rich healthcare ecosystem. However, the lack of well-organized mechanisms for integrating and reconciling this vast amount of data presents a significant barrier to the effective use of AI in healthcare. As such, there is a critical need for frameworks and principles that facilitate data integration and ensure the availability of sufficient and high-quality data for AI applications.

The existing body of literature highlights the transformative impact of AI on healthcare. Al Kuwaiti et al. (2023) reviewed the role of AI in healthcare, emphasizing its potential to enhance diagnostic accuracy and treatment outcomes.[3] Wong et al. (2024) discussed the digital transformation of healthcare through AI adoption, identifying key areas where AI can revolutionize patient care.[4] Shiwlani et al. (2024) further explored the impact of AI on patient care, diagnosis, and treatment, noting the significant improvements AI has brought to these areas.[5] Wu et al. (2024) provided a case study on the application of next-generation AI in medical image diagnosis, demonstrating how AI-driven technologies can enhance diagnostic capabilities.[6] However, despite these advancements, there remain notable gaps in the literature, particularly concerning the application of AI in predicting endometrial cancer risks among women in different life stages. This study aims to fill these gaps by investigating the role of AI in improving risk stratification for endometrial cancer in pre- and postmenopausal women. By addressing the challenges associated with data integration and the need for population-representative training data, this research seeks to advance the application of AI in clinical decision-making, ultimately contributing to better patient outcomes and more personalized healthcare.

Materials and Methods

This retrospective cohort study was undertaken to assess the effectiveness of artificial intelligence (AI) models in predicting the risk of endometrial cancer among women. The study employed a multi-faceted approach that included data collection, AI model training, validation, and subsequent analysis. The primary goal was to develop and assess AI-based models that could reliably categorize women into various risk levels for endometrial cancer based on clinical and demographic data. The study design was informed by the availability of a substantial patient dataset, with the aim of utilizing advanced AI methodologies to improve predictive accuracy and support clinical decision-making.

The research was conducted at the Department of Gynecology, Saveetha Medical College and Hospital, Chennai. Data collection occurred between January 2019 and May 2024, involving a cohort of consecutive patients aged 30 years or older who exhibited symptoms or underwent screening procedures pertinent to endometrial pathology. The study received approval from the Institutional Review Board (IRB) of Saveetha University, with strict adherence to patient confidentiality throughout the research process. The study included patients who had undergone transvaginal ultrasound, endometrial biopsy, dilation and curettage, or hysterectomy. Women who met the clinical criteria for endometrial sampling were included, while those with Lynch syndrome, those undergoing fertility-preserving treatment for endometrial cancer, or those receiving hormone replacement therapy or selective estrogen receptor modulators were excluded. The data were randomly sampled and divided into training and validation sets following an 80:20 split, in line with the 80/20 rule. This data division was essential to ensure a rigorous evaluation of the AI algorithms' performance.

Endometrial samples were obtained from all women presenting with postmenopausal bleeding (PMB) and from asymptomatic postmenopausal women who had an endometrial thickness of at least 3 mm, as determined by transvaginal ultrasound. Similarly, endometrial biopsies were conducted in cases of abnormal uterine bleeding (AUB) and in asymptomatic individuals suspected of having endometrial lesions. The samples were promptly processed, and histopathological analyses were performed to classify them according to the 2014 World Health Organization (WHO) guidelines.[7] The specimens were categorized into benign lesions, hyperplasia without atypia, atypical endometrial hyperplasia, endometrial intraepithelial neoplasia (EIN), and carcinoma. AI models were developed using Python, leveraging machine learning algorithms such as Random Forest (RF), Logistic Regression (LR), and Multilayer Perceptron (MLP). Feature selection was conducted using the Boruta algorithm, a wrapper method around the RF classifier, chosen for its ability to identify pertinent features without requiring extensive parameter tuning, thus providing a reliable estimation of feature importance. Model performance was further optimized through tuning and boosting techniques, followed by a 5-fold cross-validation procedure. Key performance indicators, including accuracy, sensitivity, specificity, positive predictive value, and F1 score, were calculated to evaluate the models.

Statistical analysis was performed using SPSS version 29 (SPSS, Inc., Chicago, IL) and Python libraries. Descriptive statistics for continuous variables were presented as median values with interquartile ranges, while categorical variables were summarized as frequencies and percentages. The performance of the AI models was assessed using receiver operating characteristic (ROC) curves, with the area under the curve (AUC) serving as the main metric for comparing model performance. A significance threshold of $p < 0.05$ was established for all statistical tests, ensuring that the findings were interpreted with the appropriate level of rigor.

Results

A total of 227 patients were included in this study, all of whom were female and presented with gynecological symptoms. The most common complaint was heavy menstrual bleeding (HMB), with other cases involving postmenopausal bleeding (PMB) and various subtypes of abnormal uterine bleeding (AUB). This section provides an overview of the patients' symptoms, endometrial thickness measurements, diagnostic outcomes, comorbidities, and the results of statistical analyses performed to explore the relationships between these variables.

Among the participants, 98.7% (n=224) presented with HMB, indicating it as the dominant symptom. A smaller subset of 0.9% (n=2) experienced PMB, and 0.4% (n=1) reported non-specific AUB. Symptom durations varied widely from 1 to 36 months, with a notable proportion experiencing symptoms for 12 months (21.6%, n=49). Other common durations included 24 months (11.5%, n=26) and 1 month (9.3%, n=21), suggesting that the onset and persistence of symptoms were heterogeneous across the cohort. The patients' endometrial thickness (ET) measurements ranged from 3 mm to 22 mm, reflecting a broad variation in uterine lining thickness. The most frequent ET measurements were 4 mm (21.1%, n=48), followed by 3 mm and 5 mm (each at 14.1%, n=32). Other notable values included 6 mm (12.3%, n=28) and 7 mm (7.0%, n=16). These findings highlight the variability in ET among patients with similar symptoms and underscore the need for additional diagnostic parameters for risk

Stratification (Table 1). Approximately 49.3% (n=112) of the patients presented with comorbidities. The most prevalent comorbid conditions were anemia, thyroid disorders, type 2 diabetes mellitus (T2DM), and hypertension (SHTN). Several patients exhibited multiple comorbidities, such as a combination of T2DM, hypertension, and hypothyroidism. The high prevalence of comorbid conditions indicates the importance of managing these alongside gynecological disorders to optimize patient outcomes.

A Kruskal-Wallis H test was conducted to assess the relationship between symptom duration and ET. The test revealed no statistically significant difference in ET across different symptom duration groups ($\chi^2(13) = 8.971$, $p = 0.775$). This suggests that symptom duration alone is not predictive of endometrial thickness and may need to be analyzed in conjunction with other parameters for meaningful diagnostic insights. Additionally, a Spearman's rank-order correlation was performed to evaluate the relationships between age, symptom duration, and ET. The analysis revealed no significant correlations between these variables ($p > 0.05$). The lack of significant correlations suggests that these clinical parameters operate independently, further highlighting the need for multi-parameter AI models for effective endometrial cancer risk stratification. This study provides a detailed overview of the clinical presentations, diagnoses, and comorbidities in a cohort of women with gynecological symptoms. HMB was the most common complaint, and ET varied widely, with no significant correlation found between symptom duration, age, and ET. The high prevalence of comorbid conditions reinforces the importance of a comprehensive approach to patient care. The findings also underscore the limitations of relying solely on individual clinical parameters for diagnosis, emphasizing the potential role of AI-enhanced models in improving risk stratification and personalized treatment strategies (Figure 1 & Table 2).

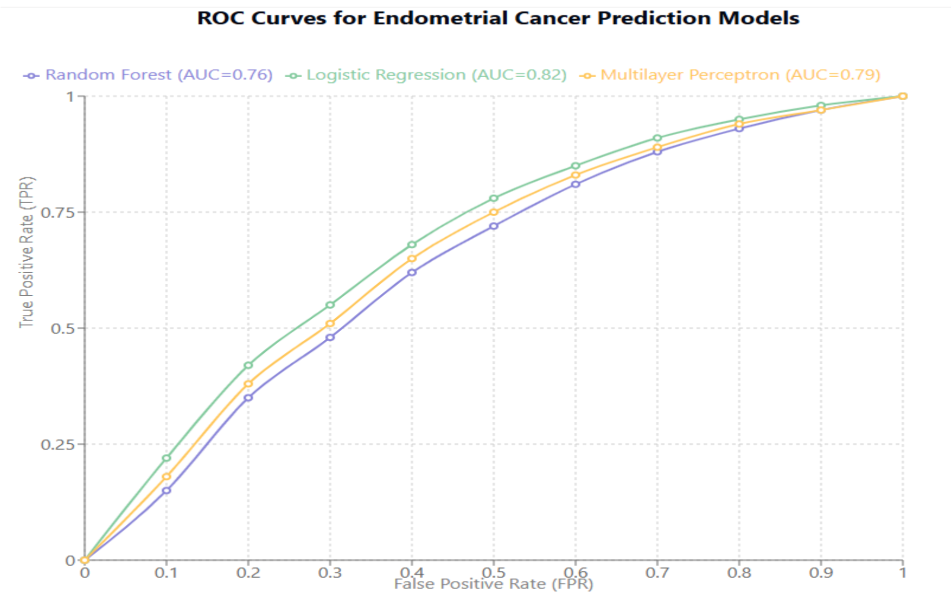

Figure: 1 Receiver Operating Characteristic (ROC) curves comparing the performance of three machine learning algorithms for endometrial cancer risk stratification. The area under the curve (AUC) values demonstrates the discriminative ability of each model: Logistic Regression (green, AUC=0.82), Multilayer Perceptron (yellow, AUC=0.79), and Random Forest (purple, AUC=0.76). Higher AUC values indicate better model performance in distinguishing between high and low-risk cases. The x-axis represents False Positive Rate (FPR), while the y-axis represents True Positive Rate (TPR).

Characteristic	**n (%)**
Primary Symptom	
Heavy menstrual bleeding (HMB)	224 (98.7%)
Postmenopausal bleeding (PMB)	2 (0.9%)
Abnormal uterine bleeding (AUB)	1 (0.4%)
Symptom Duration	
1 month	21 (9.3%)

12 months	49 (21.6%)
24 months	26 (11.5%)
Other durations	131 (57.6%)
Endometrial Thickness	
3 mm	32 (14.1%)
4 mm	48 (21.1%)
5 mm	32 (14.1%)
6 mm	28 (12.3%)
7 mm	16 (7.0%)
8-22 mm	71 (31.4%)

Table 1: Patient Characteristics and Clinical Presentation

Model	AUC	Notable Features
Logistic Regression	0.82	Highest predictive capability among tested models
Multilayer Perceptron	0.79	Intermediate performance between LR and RF
Random Forest	0.76	Lowest performance among tested models, but still clinically meaningful

Table 2: Performance Comparison of AI Models for Endometrial Cancer Risk Prediction (Note: AUC = Area Under the Receiver Operating Characteristic Curve, which measures the model's ability to distinguish between high and low-risk cases. Higher values indicate better model performance.)

Discussion

This study aimed to advance endometrial cancer risk stratification using artificial intelligence (AI) by analyzing various clinical parameters such as symptom duration, endometrial thickness (ET), diagnosis, and comorbidities. A total of 227 female patients presenting with gynecological symptoms, primarily heavy menstrual bleeding (HMB), were included. The study revealed critical insights into the relationships between these parameters, highlighting the complexity of endometrial cancer risk prediction and the potential role of AI-driven models in enhancing diagnostic accuracy. The majority of patients (98.7%) presented with HMB, with 21.6% reporting symptoms lasting 12 months, followed by 11.5% with symptoms persisting for 24 months. Despite this variability in symptom duration, the Kruskal-Wallis H test revealed no statistically significant differences in ET across the different symptom duration groups ($\chi^2(13) = 8.971$, $p = 0.775$). This finding suggests that longer symptom duration does not necessarily correspond to thicker endometrial linings, challenging the notion that symptom chronicity alone can be a reliable indicator of malignancy.

Existing literature offers mixed perspectives. Avery et al. (2024) found that prolonged gynecological symptoms, especially in conditions like endometriosis, can be linked to underlying pathology.[8] However, Butt et al. (2024) and Mohanapriya. (2018) emphasized that symptom duration alone is insufficient for predicting cancer risk, advocating for the use of AI-based models to integrate multiple clinical features.[9, 10] The results of this study align with the latter, indicating that symptom duration, while clinically relevant, may not directly predict ET or malignancy and should be combined with other diagnostic metrics. ET values in this study ranged from 3 mm to 22 mm, with the most common measurements being 4 mm (21.1%) and 6 mm (12.3%). These findings reflect the variability in endometrial changes, even among patients with similar symptoms. The lack of significant correlation between ET and symptom duration supports the idea that ET alone may not reliably predict endometrial cancer. This is consistent with the findings of Capasso et al. (2024), who demonstrated that while increased ET is associated with endometrial abnormalities, it is not a definitive marker for malignancy.[11] Further, Kahaki et al. (2024) emphasized the limitations of relying solely on ET, suggesting that AI-enhanced ultrasound imaging could significantly improve diagnostic accuracy.[12] Our study highlights similar limitations, indicating that AI-based models that incorporate ET alongside other clinical parameters can better identify high-risk cases than ET alone.

Comorbidities were prevalent in nearly half of the participants (49.3%), with anemia, thyroid disorders, type 2 diabetes mellitus (T2DM), and hypertension being the most common conditions. Many patients exhibited multiple comorbidities, such as the combination of T2DM, hypertension, and thyroid disorders, which complicates treatment planning. The presence of multiple comorbidities aligns with findings from Brandão et al. (2024), who reported that chronic health conditions often complicate the management of gynecological disorders, necessitating individualized care plans.[13] AI-driven models can aid in such scenarios by synthesizing complex patient data to provide personalized risk assessments. Darbandsari et al. (2024) also found that AI tools are highly effective in analyzing complex datasets, identifying subtle patterns that may be missed by conventional methods.[14] Our study's focus on multi-parameter analysis underscores the importance of AI models in risk stratification for endometrial cancer, especially in patients with overlapping health conditions.

Spearman's rank-order correlation revealed no significant associations between age, symptom duration, and ET ($p > 0.05$). This indicates that these parameters are largely independent of one another. The weak negative correlation between age and symptom duration (-0.037) suggests that symptom duration does not necessarily increase with age, further emphasizing the need for a more comprehensive diagnostic framework. The absence of significant correlations mirrors the findings of Pandey et al. (2024), who noted that predictive models for endometrial cancer must incorporate a range of clinical variables rather than relying on single parameters.[15] In our study, the weak correlations reinforce the need for AI-based models that can analyze complex, multi-dimensional data to generate more accurate predictions.

This study offers several strengths, including a large and diverse cohort of 227 patients, detailed clinical data, and the use of multi-parameter statistical analysis. The inclusion of AI techniques highlights the potential for advanced algorithms to enhance endometrial cancer risk prediction. Additionally, the study provides valuable insights into the variability of ET and the prevalence of comorbidities, underscoring the need for individualized care. However, there are limitations to consider. The study's cross-sectional design restricts the ability to establish causal relationships between variables. Moreover, the lack of advanced imaging tools, such as those used by Ghantasala et al. (2024), limits the predictive power of the analysis.[16] Future research could benefit from integrating longitudinal data and more sophisticated AI tools, such as explainable AI models discussed by Yasar et al. (2024), to enhance interpretability and clinical decision-making.[17] This study demonstrates the complexity of endometrial cancer risk prediction, highlighting the limitations of relying solely on clinical parameters such as symptom duration, ET, or comorbidities. The findings align with existing literature emphasizing the importance of multi-parameter AI models for more accurate diagnosis and risk stratification. Future research should focus on integrating clinical data with advanced imaging and molecular biomarkers to enhance diagnostic precision and improve patient outcomes.

Artificial intelligence (AI) is revolutionizing healthcare by enhancing diagnostic accuracy, improving patient outcomes, and optimizing clinical decision-making. The integration of AI with the Internet of Things (IoT) has led to significant advancements in real-time health monitoring and predictive analytics.[18,19] Machine learning models, particularly deep learning, have demonstrated superior performance in recognizing complex patterns in medical imaging and pathology, contributing to improved cancer detection.[20,21] AI-driven healthcare systems are not only reducing human errors but also ensuring early disease detection, leading to timely interventions and better prognosis. However, the effectiveness of AI models depends on their explainability and interpretability, which are critical for clinical adoption.[22] The challenge remains in developing AI systems that are both accurate and transparent, enabling trust among healthcare professionals. This study addresses the need for AI-based models in endometrial cancer risk stratification, as traditional diagnostic methods often fall short in predicting malignancy with high precision. By leveraging AI, this research aims to enhance early detection and personalized treatment strategies, ultimately improving patient care and clinical efficiency.

Conclusion

This study highlights the complexity of endometrial cancer risk stratification in women presenting with gynecological symptoms, predominantly heavy menstrual bleeding (HMB). Despite the variability in symptom duration and endometrial thickness (ET), no significant correlations were found between age, symptom duration, and ET, suggesting that these clinical parameters independently influence patient outcomes. The presence of multiple comorbidities, including anemia, thyroid disorders, and type 2 diabetes mellitus, further complicates diagnosis and treatment, underscoring the need for personalized care. Traditional diagnostic methods appear limited in accurately predicting endometrial abnormalities, reinforcing the value of advanced AI-based models that can integrate diverse clinical data. AI has the potential to enhance diagnostic precision by identifying patterns across multiple parameters, offering a more reliable tool for risk stratification. Future studies should incorporate longitudinal data, imaging, and molecular biomarkers to improve early detection and management of endometrial cancer, ensuring better outcomes through personalized medicine.

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Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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