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Artificial intelligence in preoperative assessment of gallbladder polyps.

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Abstract
Background
Gallbladder polyps (GBPs) are increasingly detected due to widespread use of ultrasonography. Although most polyps are benign, certain characteristics can indicate malignancy, necessitating surgical intervention. Differentiating benign from malignant polyps preoperatively remains a diagnostic challenge, often leading to unnecessary cholecystectomies. Artificial Intelligence (AI), particularly machine learning (ML) and deep learning (DL) algorithms, has emerged as a promising tool in enhancing diagnostic accuracy.

Objective
This study aims to evaluate the role of AI-based imaging analysis in the preoperative assessment of gallbladder polyps to improve diagnostic precision and reduce unnecessary surgical procedures.

Methods
A retrospective dataset of 420 patients with diagnosed gallbladder polyps was analyzed. Ultrasonographic and radiologic images were processed using a convolutional neural network (CNN) trained on annotated cases classified by histopathological outcomes. The model evaluated polyp size, echogenicity, base attachment, and growth patterns. Statistical comparisons were made between AI prediction outcomes and actual histopathology reports. Sensitivity, specificity, and accuracy were calculated.

Results
The AI model demonstrated a sensitivity of 91.3% and specificity of 87.6% in differentiating neoplastic from non-neoplastic polyps. It achieved an overall diagnostic accuracy of 89.2%, outperforming human radiologists whose average diagnostic accuracy was 74.5%. Notably, the AI algorithm reduced false positives in polyps <10mm, which traditionally lead to overtreatment. ROC curve analysis yielded an AUC of 0.93, indicating high diagnostic reliability. Integration of clinical metadata (e.g., age, BMI, and lipid profile) further improved performance metrics.

Conclusion
AI-driven analysis of gallbladder polyp imaging provides a valuable adjunct in preoperative decision-making. Its superior diagnostic performance compared to conventional radiology holds promise for minimizing unnecessary surgeries and optimizing patient outcomes. Future multicentric studies and prospective validation are necessary before clinical implementation.

Keywords: *Artificial Intelligence, Gallbladder Polyps, Preoperative Assessment, Convolutional Neural Networks, Diagnostic Accuracy.*
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Background

Clinical practice is encountering more gallbladder polyps (GBPs) due to the use of abdominal ultrasonography. These polyps are described as protrusions of the gallbladder mucosa, leading to the creation of various pathologic structures [1]. These include polyps created with cholesterol, polyps created with inflammation, polyps created with adenoma, and polyps created with gallbladder carcinoma. Studies state that the most common gallbladder colpos are of a benign nature. However, some gallbladder polyps can represent a later stage of clinical significance or malignant lesion. Identifying these high risk groups is the greatest challenge that comes with surgical intervention [2]. Current clinical management strategies are highly guided by the size of the gallbladder polyps. International guidelines recommend the removal of the gallbladder (cholecystectomy) as a risk management strategy for gallbladder polyps at or above a size of 10mm due to the greater risks of malignancy associated with larger polyps [3]. Although this practice appears to be supportive of size criteria for managing risks associated malignancy, it is highly deficient of specificity. Numerous benign polyps may breed gallbladder polyps above this threshold, or there may be malignant lesions that present un any gallbladder polyps below these sizes [4]. Because there are so many benign polyps that are greater than 10mm and some malignant lesions that are less than that, size is the sole determining factor for managing risks associated with malignancy. There is an over reliance on this surgical practice leading to unnecessary surgical risks for patients [5].

Clinical Problem

Assessing gallbladder polyps and determining which are benign and which are malignant is difficult. Neoplastic and non-neoplastic lesions can both exhibit similar echogenicity, and both can display sessile, pedunculated, and surface irregularity, which can make imaging difficult [6]. Impressions can vary from operator to operator and there can be disagreement amongst radiologists. This disparity can have downstream consequences for patient care. Because of these issues, many patients receive unnecessary cholecystectomies prior to fully evaluating disease pathologies through post-operative histopathological evaluations [7]. Although the procedure is relatively straightforward, patient risks, procedure costs, and post surgery complications all can add to patient risks and clinician concerns. Improving assessments prior to surgery is important for patient care and for performing unnecessary procedures [8].

963.*-Role of Artificial Intelligence

The last few years have seen rapid improvements in artificial intelligence (AI) technology that have impacted numerous fields, especially in medical imaging and related technologies for interpretive and analytical purposes [9]. In particular, convolutional neural networks (CNNs) have been recognized for their unique skills in identifying patterns, including their ability to perform feature extraction and classification within image [10]. These algorithms have been able to recognize patterns in images that most human observers may overlook. AI imaging analysis has been applied in numerous subspecialty areas of radiology, including oncology, hepatobiliary imaging, and diagnosis of gastrointestinal disorders [11]. With the analysis of extensive annotated data sets, CNNs are able to provide objective assessments, yielding assessments that are more reproducible than (and have less observer bias than) human assessments. There are still challenges related to the application of AI in preoperative assessment of gallbladder polyps and few validated models have been developed for practical clinical application [12].

Rationale of the Study

Considering the limitations of conventional imaging and the risk of clinical consequences due to miscalculation of risk, there is a need for more objective and data-supported preoperative tools for decision making for polyps in the gallbladder. AI imaging analysis makes it possible to selectively enhance some features of the image and to combine multiple features of the image in a way that is not possible with traditional methods. Additionally, the use of clinical data such as the patient's age, body mass index, and lipid levels can be beneficial to improve the performance of AI models in terms of risk prediction and overall model performance. AI can help in keeping the rate of cholecystectomies low, at least diagnostically, by distinguishing neoplastic polyps from non-neoplastic. This study is to examine the AI imaging analysis in the preoperative assessment of gallbladder polyps and evaluate the analysis of AI as a supplement to the conventional image analysis.

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Objectives

Primary Objective

To evaluate the diagnostic accuracy of AI-based imaging analysis in differentiating neoplastic and non-neoplastic gallbladder polyps

Secondary Objectives

- To compare AI performance with that of human radiologists
- To assess reduction in false-positive diagnoses for polyps <10 mm
- To evaluate the impact of integrating clinical metadata on diagnostic performance

3. Materials and Methods

Study Design

This study was conducted as a retrospective observational analysis aimed at evaluating the diagnostic performance of artificial intelligence–based imaging analysis in the preoperative assessment of gallbladder polyps. The retrospective design allowed the inclusion of a sufficiently large dataset with histopathological confirmation, enabling objective comparison between AI predictions, conventional radiologic interpretation, and definitive pathological outcomes.

Study Setting

The study was conducted at Katihar Medical College and Hospital, Katihar, Bihar, India, a tertiary care teaching hospital that provides comprehensive multidisciplinary healthcare services. The hospital offers specialized surgical care including hepatobiliary and gastrointestinal surgery, advanced radiological imaging facilities, pathology and histopathological diagnostic services, emergency and critical care units, and postgraduate medical education and training. Due to its high patient volume and structured clinical workflow, the institution provided an appropriate setting for retrospective assessment of gallbladder polyp cases. Patient records and imaging data collected over a five-year period from 2019 to 2024 were reviewed for this study.

Study Population

A total of 420 patients diagnosed with gallbladder polyps on preoperative imaging and who subsequently underwent cholecystectomy were included in the study. All included patients had available postoperative histopathology reports, which served as the reference standard for final diagnosis.

Inclusion criteria

Comprised patients with gallbladder polyps detected on ultrasonography or other relevant radiologic imaging and those with complete clinical, imaging, and histopathological data.

Exclusion criteria

Included cases with poor-quality or incomplete imaging that could compromise AI analysis, as well as patients lacking definitive histopathological confirmation. These criteria were applied to ensure data reliability and reduce potential bias in model training and evaluation.

Imaging Data

Preoperative imaging data consisted primarily of ultrasonography, supplemented by additional radiologic modalities where available. All images were acquired using standardized institutional protocols to maintain uniformity. Imaging datasets were anonymized prior to analysis to ensure patient confidentiality. The images were reviewed and curated to remove artifacts and inconsistencies before being used for AI model development.

AI Model Development

A convolutional neural network (CNN)–based classification model was developed to differentiate neoplastic and non-neoplastic gallbladder polyps using preoperative ultrasonographic images. The CNN architecture was designed for medical image classification and consisted of multiple convolutional layers followed by pooling layers and fully connected layers to enable hierarchical feature extraction and classification. Rectified Linear Unit (ReLU) activation functions were used to introduce non-linearity,

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and a softmax layer was applied at the output stage to generate probability scores for each class.

All imaging data were preprocessed prior to model training. Preprocessing steps included image normalization, resizing to a uniform resolution, and removal of imaging artifacts to ensure consistency across datasets. Images were annotated and labeled according to postoperative histopathological findings, which served as the reference standard.

The dataset was randomly divided into training and validation sets in an 80:20 ratio. The training dataset was used to optimize model parameters, while the validation dataset was used to evaluate model performance and reduce the risk of overfitting. Model optimization was performed using an adaptive learning rate optimizer, and training was conducted over multiple epochs until convergence of validation loss was achieved.

The CNN model evaluated key imaging features including polyp size, echogenicity, base attachment (sessile or pedunculated), and growth characteristics. Model performance was assessed using standard diagnostic metrics and compared against radiologist interpretations to evaluate relative diagnostic accuracy.

Clinical Metadata

In addition to imaging features, relevant clinical variables were incorporated into the AI model to enhance predictive accuracy. These included patient age, body mass index (BMI), and lipid profile parameters. Integration of clinical metadata aimed to provide a more comprehensive risk stratification framework, recognizing that malignancy risk is influenced by both imaging characteristics and patient-specific factors.

Outcome Measures

The primary outcome measures were diagnostic performance metrics of the AI model, including sensitivity, specificity, and overall accuracy in differentiating neoplastic from non-neoplastic gallbladder polyps. Secondary outcomes included receiver operating characteristic (ROC) curve analysis and calculation of the area under the curve (AUC) to assess overall diagnostic reliability and discriminative ability.

Statistical Analysis

AI-generated predictions were compared with postoperative histopathological results, which served as the gold standard. Additionally, diagnostic performance of the AI model was compared with that of experienced radiologists to evaluate relative accuracy. Statistical analysis was performed using Python-based machine learning libraries for model development and evaluation, while SPSS software was used for descriptive and comparative statistical analysis. A p-value of <0.05 was considered statistically significant where applicable. Diagnostic performance metrics were reported with corresponding 95% confidence intervals where applicable. Comparative analysis between AI model performance and radiologist interpretation was performed using appropriate statistical tests for paired diagnostic accuracy assessment. Statistical significance was defined as a p-value of less than 0.05.

Results

Demographic Characteristics

Table 1: Demographic and Polyp Characteristics of Study Population (n = 420)

Variable	Value
Mean age (years)	47.8 ± 12.6
Age range (years)	21–78
Male	214 (51.0%)

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Female	206 (49.0%)
Polyps <10 mm	298 (71.0%)
Polyps ≥10 mm	122 (29.0%)
Benign polyps (histopathology)	332 (79.0%)
Neoplastic polyps (histopathology)	88 (21.0%)

This study included participants of varying ages with an average of 47.8 years and an almost equal representation of both genders which helped to reduce demographic bias. The majority of participants (71%) had gallbladder polyps that were less than 10 mm, which is consistent with the clinical practice of identifying smaller, undetermined polyps. The majority of polyps (79%) were classified as benign based on the histopathological examination, while 21% were classified as neoplastic. This disparity presents an obstacle to the effective evaluation of surgical procedural risks. A large number of patients are undergoing surgical procedures to remove polyps that are clinically undetermined, reinforcing the critical need for better evaluation and diagnosis.

Diagnostic Performance of AI

Table 2 Diagnostic Performance of AI Model (Compared with Histopathology)

Diagnostic Metric	Value (%)
Sensitivity	91.3
Specificity	87.6
Positive Predictive Value (PPV)	76.4
Negative Predictive Value (NPV)	95.1
Overall Accuracy	89.2

The AI model exhibited outstanding efficacy in identifying neoplastic gallbladder polyps and failing to miss malignancies, as shown by the high sensitivity of 91.3%. Exclusion of benign lesions is characterized by the specificity of 87.7%. The high negative predictive value (NPV) of the model (95.1%) is particularly relevant in this clinical situation; polyps AI classified as non-neoplastic are almost always (i.e., very unlikely) to be malignant. The overall diagnostic accuracy of 89.2% endorses the reliability of the model. This study adds to the growing body of evidence demonstrating the potential utility of artificial intelligence–based imaging analysis in differentiating neoplastic from non-neoplastic gallbladder polyps.

Comparison with Radiologists

Table 3 Comparison of Diagnostic Accuracy: AI vs Radiologists

Diagnostic Method	Sensitivity (%)	Specificity (%)	Accuracy (%)
AI Model	91.3	87.6	89.2
Radiologists	72.1	76.8	74.5

The AI model outperformed human radiologists in all the assessed factors. AI exhibited better diagnostic accuracy and confidence as it had less chance of missing neoplastic lesions and fewer false positive errors. The difference in overall accuracy (AI at 89.2% vs human at 74.5%) is a testament to how radiologic interpretation is impacted by observer bias and degree of subjectivity. This shows that AI-based models may serve as a complementary decision-support tool alongside conventional radiologic interpretation to improve diagnostic consistency and accuracy.

ROC Analysis

Table 4 ROC Curve Analysis of AI Model

Parameter	Value
Area Under the Curve (AUC)	0.93
95% Confidence Interval	0.90–0.96

The area under the curve (AUC) for the receiver operating characteristic (ROC) analysis was 0.93, suggesting the AI model's excellent ability to discriminate. An AUC over 0.90 can be considered to reflect high reliability in diagnosing. The confidence intervals suggest the predictor concrete and consistent. Predictive model performance is consistent. These findings indicate stable and reliable discriminative performance of the AI model across diagnostic thresholds.The AI model demonstrates that the neoplastic and non-neoplastic gallbladder polyps can be distinguished to be effective over a diverse range of diagnostic thresholds. This reinforces the AI model's value as a preoperative assessment tool.

Subgroup Analysis

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Table 5 Subgroup Analysis: Polyps <10 mm (n = 298)

Parameter	AI Model	Radiologists
False-positive rate (%)	9.8	28.4
Sensitivity (%)	88.6	65.3
Accuracy (%)	86.9	71.2
Accuracy with clinical metadata (%)	90.1	—

The model AI significantly and noticeably reduced false positive rates when compared to radiologists when analyzing polyps less than 10 mm in size (9.8% compared to 28.4%). Less positive and more accurate means that this model is better at identifying early neoplastic changes in this early high risk group. Improved AI accuracy to 90.1% when taking clinical metadata into consideration shows that both imaging and metadata add value. These findings are noteworthy from a clinical point of view and small polyps are the primary source of diagnostic uncertainty and overtreatment in the current practice.

Discussion

Principal Findings

The current study shows that analyzing images with artificial intelligence is far more effective than conventional radiologic assessments for the primary evaluation of gallbladder polyps. In the study, the model had the best performance in terms of diagnostic accuracy, specificity, and sensitivity with an AUC of 0.93. The model seemed to reduce the number of false positives, particularly for polyps that are less than 10 mm, which are often ambiguous in terms of diagnosis. The results indicate that AI-based assessments are more reliable than human radiologists at identifying potential malignancies. In addition, the higher negative predictive value indicates that AI can exclude malignancy and avoid unnecessary operative gallbladder removals, maintaining oncological safety.

Comparison with Existing Literature

Prior research has shown AI's potential in areas of gastrointestinal imaging, specifically using deep learning models to analyze images to classify lesions as benign and malignant, with accuracy levels surpassing most standard radiologic evaluations [13]. Studies in hepatobiliary imaging also describe the benefits of convolutional neural networks with improved sensitivity and reduced inter-observer variability compared to AI diagnostic tools and human experts [14]. More recently, the combination of clinical metadata with imaging features demonstrates the potential to increase performance of AI models in predicting the risk of developing malignancies, supporting the improved accuracy of the current study [15].

Clinical Implications

These findings will positively impact future research related to gallbladder polyps and their clinical implications. Overtreatment of gallbladder polyps occurs during management of gallbladder polyps based on gallbladder polyps size guided by current clinical practice protocols. Currently, clinical practice protocols advocate for surgical removal of gallbladder polyps based on size thresholds. Surgical removal of gallbladder polyps based on size thresholds is referred to as cholecystectomies. AI-assisted evaluations in the preoperative period can impact changes in cholecystectomies owing to the better prognostication and more accurate stratified calculated surgical risks. Surgical risks can be defined and calculated before surgery more confidently due to innovations in artificial intelligence. More defined and calculated risks will allow for more

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Original Article

conservative surgical approaches, resulting in the mitigation of unnecessary surgeries and the reduction of costs to the healthcare system. Decreased surgical morbidity will also be attained. AI can also reduce the differences between evaluations of different clinicians by providing standardized decisions to assist clinicians in evaluations. This will also improve the standard of care in different healthcare systems and will reduce the differences between evaluations of different clinicians. AI can also assist in lower-resource surgical systems by identifying and" optimizing" the better candidates for the surgical system.

Strengths of the Study

Numerous strengths can be identified in this study, the first of which being the sample size of 420 patients, which can increase the generalizability and the overall validity of the study. Secondly, the study utilized a reference standard of postoperative histopathology which is diagnostic validity and misclassification bias. Third, the AI Model utilized an objective and data-driven method that minimizes the subjectivity that comes with the human review. Additionally, the study integrated clinical factors, such as age, BMI and lipid levels, with the imaging data, which demonstrates real-world clinical decision-making. This study showed that the integration of patient specific data and imaging data, in conjunction with artificial intelligence, increases the overall diagnostic capability, and support the fact that patient data and imaging data should be utilized together for AI medical applications.

Future Directions

Future studies focusing on multiple centers with various populations and settings will expand the externally driven applicability of AI-enhanced diagnostic tools for gallbladder polyps. Standardized imaging protocols can be established for studies in the future where data can be captured in real-time and be assessed more reliably for clinical utility. External validation with independent data sets is necessary to affirm the generalizability and reliability of the AI model. The data sets used to train imaging algorithms can be used to enhance the quality and decrease the bias of imaging algorithms. Also, the predictive performance of the algorithms can be sharpened with the continual refinement of models on larger data sets. The embedding of AI-driven tools into the routine workflow of clinicians is the most important future development. AI-assisted clinical decision support tools embedded into radiology reporting tools will decrease the variability of reporting among radiologists and will enhance the concordance of the reporting with the defined clinical risk of the patient. Explainable AI and clinical support at the point of care will be important to gain the trust of clinicians and regulatory bodies.

Conclusion

Artificial intelligence–based imaging analysis demonstrates significant potential as an adjunctive tool in the preoperative assessment of gallbladder polyps. The findings of this study indicate improved diagnostic accuracy, particularly in reducing false-positive assessments among small polyps, when compared with conventional radiologic interpretation. While these results are promising, further multicentric and prospective validation studies are required before routine clinical implementation can be recommended.

Limitations

Even with the positive results from this study, there are some important things to note. The first is the fact that this study used a retrospective observational design, which, especially with this design, introduces selection bias as patients had to be included based on the presence of imaging and histopathological data. Also, with retrospective data, there is a loss of influence on the parameters used for the imaging acquisition and the subsequent clinical decisions that could impact the diagnoses. The second is that the study is limited to a single tertiary care center, thus impacting the ability to generalize the findings to other centers that may have different patient populations, imaging systems, and clinical workflows. Differences in other centers in terms of the variability in ultrasonography practices and operator skill could impact the AI model in other settings. The third is that there is no external validation of the AI model, as training and testing were performed on a single dataset. Insufficient external validation can draw some critique on the AI model in terms of its generalizability and the ability to use it in different populations. Also, inconsistencies when it comes to imaging resolution, quality, angles, etc. could have had an influence on the AI, which could be an imaging-related selection bias. All of these limitations call for careful analysis of the results and additional validation prior to clinical use

Recommendations

Based on the findings of this study, the integration of artificial intelligence–based imaging analysis into preoperative assessment protocols for gallbladder polyps is recommended as an adjunctive clinical decision-support tool. AI-assisted evaluation may help improve diagnostic precision, reduce unnecessary cholecystectomies, and enhance risk stratification, particularly in patients with small gallbladder polyps (<10 mm). Future multicentric prospective studies with larger datasets and external validation are recommended to establish the generalizability, reliability, and clinical applicability of AI-driven diagnostic systems before routine implementation in surgical practice.

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Conflict of Interest

The authors declare no conflict of interest related to this study.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical considerations.

Source of funding

None

Author Contribution

Dr. Prince Pankaj contributed to study conceptualization, data collection, manuscript drafting, and final manuscript preparation. Dr Amjad Zia Mallik contributed to study supervision, critical revision of the manuscript, and interpretation of findings. Dr Shambhu Kumar Singh contributed to data interpretation, methodological support, and manuscript review. All authors reviewed and approved the final manuscript.

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