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EsoCancer AI: Intelligent Esophageal Adenocarcinoma Detection System Using Deep Learning

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ABSTRACT: Esophageal adenocarcinoma is one of the most aggressive and rapidly progressing gastrointestinal malignancies, with a poor prognosis when detected at advanced stages. Early detection significantly improves patient survival rates, making accurate and timely diagnosis critical. This paper presents EsoCancer AI, an intelligent medical image analysis platform designed to detect esophageal adenocarcinoma from endoscopic images using deep learning. The proposed system employs a Convolutional Neural Network (CNN) model built using TensorFlow and Keras to analyze endoscopy images and classify them as Normal, Adenocarcinoma, or Barrett's Esophagus. The system automatically preprocesses input images to ensure prediction accuracy across different devices and imaging conditions. In addition to disease detection, EsoCancer AI integrates confidence scoring, probability distribution analysis, and detailed clinical interpretation reports to assist clinicians in diagnosis. The platform includes a secure user authentication system, patient dashboard, and downloadable analysis reports, making it suitable for clinical deployment. The modular architecture consisting of a core diagnostic server ensures scalable performance across web platforms. The proposed system aims to improve early detection rates of esophageal adenocarcinoma, reduce diagnostic errors, and enable clinicians to make data-driven decisions.

KEYWORDS: Esophageal Cancer Detection, Deep Learning, Medical Image Analysis, Convolutional Neural Network, Adenocarcinoma, Endoscopy AI, Clinical Decision Support

I. INTRODUCTION

Esophageal cancer is the eighth most common cancer worldwide and the sixth leading cause of cancer-related deaths globally. Among its two major subtypes, esophageal adenocarcinoma (EAC) has shown a dramatic increase in incidence over recent decades, particularly in Western countries. EAC typically arises from Barrett's esophagus, a precancerous condition caused by chronic gastroesophageal reflux disease (GERD), in which the normal squamous epithelium of the lower esophagus is replaced by columnar epithelium.

The prognosis of esophageal adenocarcinoma is strongly stage-dependent. When detected at early stages (Stage I), the five-year survival rate can exceed 80%. However, due to the lack of specific early symptoms, most patients are diagnosed at advanced stages, resulting in survival rates dropping below 20%. This highlights the critical importance of early detection through screening programs and advanced diagnostic tools. Traditional diagnosis of esophageal adenocarcinoma relies on endoscopy followed by biopsy and histopathological analysis. While endoscopy is effective, it is time-consuming, operator-dependent, and subjective. Subtle mucosal changes indicative of early adenocarcinoma or Barrett's esophagus can easily be missed during routine visual inspection, especially in high-volume clinical settings.

EsoCancer AI is an AI-driven platform designed to address these diagnostic challenges by integrating advanced image-processing techniques and deep learning-based analysis. The proposed system enables automatic detection and classification of esophageal adenocarcinoma from uploaded endoscopy images, provides confidence scoring, and generates detailed clinical interpretation reports. By incorporating CNN-based classification, the platform offers a comprehensive understanding of esophageal pathology to support clinicians in accurate and timely diagnosis.

Beyond disease detection, EsoCancer AI improves diagnostic workflow efficiency through features such as automated report generation, analysis history tracking, and a user-friendly dashboard. The system's scalable architecture ensures compatibility with both clinical and research environments, thereby supporting accessibility across a wide range of healthcare settings. By combining intelligent insights, automation, and seamless usability, EsoCancer AI contributes to



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a smarter approach to early esophageal cancer detection, ultimately helping clinicians enhance diagnostic accuracy and patient outcomes.

II. RELATED WORK

Recent advancements in artificial intelligence and computer vision have significantly contributed to the development of intelligent medical imaging systems. Several studies have explored the application of deep learning techniques for gastrointestinal cancer detection, endoscopy image analysis, and clinical decision support.

Esteva et al. (2017) demonstrated that deep convolutional neural networks could classify skin cancer with dermatologist-level accuracy, establishing a strong foundation for AI-based cancer detection systems. This work highlights the potential of image-based diagnosis systems, which forms a core component of the EsoCancer AI platform.

Codipilly et al. (2022) demonstrated that AI-based endoscopy image analysis using deep learning models significantly improved detection rates of Barrett's esophagus and esophageal adenocarcinoma compared to standard endoscopic surveillance. Their work established deep learning as a viable tool for gastrointestinal cancer screening.

de Groof et al. (2020) proposed a deep learning system for automatic detection of Barrett's neoplasia during endoscopy, demonstrating sensitivity and specificity comparable to expert endoscopists. Their system utilized a convolutional neural network trained on a large dataset of Barrett's esophagus images, highlighting the feasibility of real-time AI-assisted endoscopy.

He et al. (2016) proposed ResNet (Residual Neural Network), a deep neural network architecture using skip connections that enables training of very deep networks. ResNet has been widely adopted in medical image classification tasks due to its superior feature extraction capabilities and resistance to vanishing gradient problems.

Guo et al. (2020) explored transfer learning approaches for esophageal cancer detection, demonstrating that pre-trained CNN models fine-tuned on endoscopy datasets could achieve high accuracy with limited training data. Such transfer learning techniques are particularly important for medical imaging applications where large annotated datasets are scarce.

In addition to visual analysis, several studies emphasize the importance of integrating clinical metadata such as patient age, GERD history, and body mass index with image-based features to improve the reliability of esophageal cancer prediction systems. Integrating clinical data with deep learning models enhances the diagnostic accuracy and enables proactive clinical decision-making.

III. PROPOSED ALGORITHM

The proposed EsoCancer AI system is designed to detect esophageal adenocarcinoma automatically using machine learning and provide intelligent clinical interpretation for physicians. The system integrates image processing, deep learning, confidence analysis, and AI-based report generation to improve diagnostic decision-making.

The algorithm is divided into multiple modules including image acquisition, disease detection, confidence analysis, clinical report generation, and result management. These modules work together to provide real-time esophageal pathology analysis and actionable clinical insights.

3.1 Image Acquisition and Pre-Processing

The first stage of the proposed system is capturing the endoscopy image from the user through a web interface. The uploaded image is preprocessed before being passed to the machine learning model.

The preprocessing stage includes:

- Converting the image to RGB format
- Resizing the image to 224×224 pixels
- Normalizing pixel values to $[0, 1]$ range for better model accuracy
- Applying standardization using ImageNet mean and standard deviation

The processed image is then converted into a tensor format suitable for CNN model inference.

$I_p = \text{Normalize}(\text{Resize}(I, 224 \times 224))$



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Where: I = input endoscopy image; Ip = processed image

This preprocessing step ensures that all images are standardized before classification, maintaining prediction accuracy across different endoscopy imaging systems.

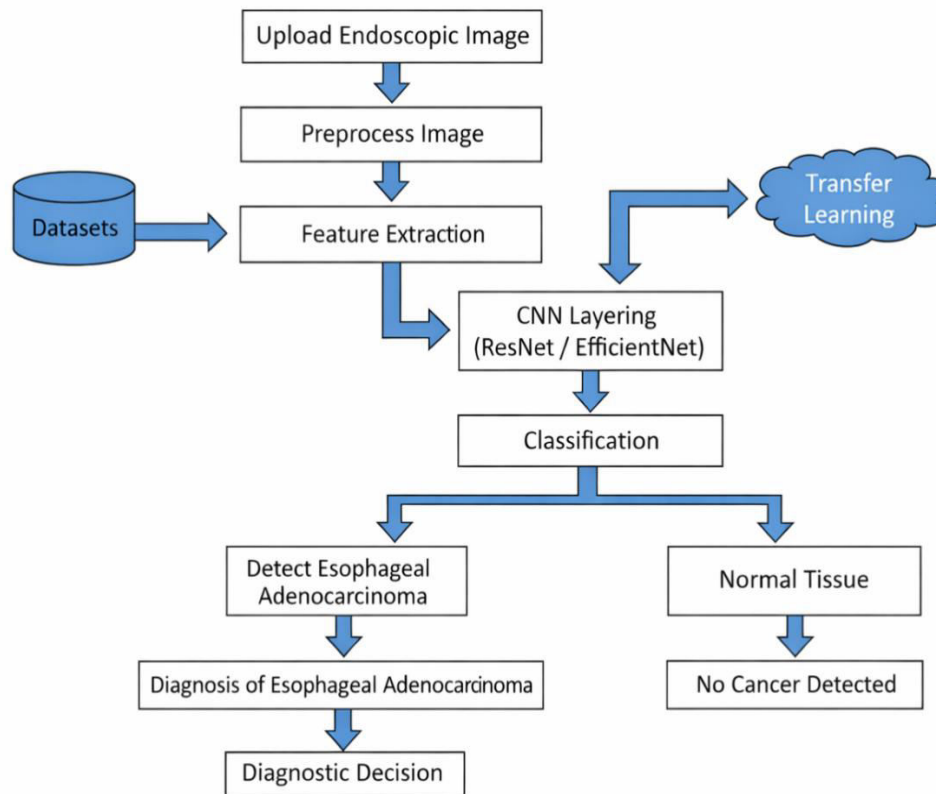


Fig.3.1.1. methodology for detecting esophageal adenocarcinoma

3.2 CNN-Based Esophageal Disease Detection

After preprocessing, the image is passed to the trained Convolutional Neural Network (CNN) model. The model extracts visual features such as mucosal texture patterns, color variations, surface irregularities, and vascular patterns to identify esophageal pathology.

The CNN model produces a probability vector representing the likelihood of different disease classes: Normal, Adenocarcinoma, and Barrett's Esophagus. The final disease prediction is calculated using the maximum probability value.

$$D = \text{argmax}(\text{CNN}(I_p))$$

Where: CNN = trained convolutional neural network model; D = predicted disease class.

The system also calculates the confidence score, which represents the reliability of the prediction on a scale of 0 to 100%. Confidence Score = $\max(\text{softmax}(\text{CNN}(I_p))) \times 100$

A confidence level above 85% is classified as High Confidence, 60-85% as Moderate Confidence, and below 60% as Low Confidence, requiring clinical review.

3.3 Prediction Distribution Analysis

The system performs comprehensive prediction distribution analysis to provide clinicians with a complete picture of the model's diagnostic assessment. For each analyzed image, the system generates a probability distribution across all three diagnostic classes.

The analysis includes:



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- Class probability bar chart showing likelihood of each diagnosis
- Confidence distribution donut chart showing Normal Confidence vs Uncertainty
- Detailed confidence score with visual progress indicator
- Risk stratification based on prediction confidence levels

This multi-dimensional analysis helps clinicians understand not just the primary diagnosis but also the model's uncertainty, enabling better-informed clinical decisions.

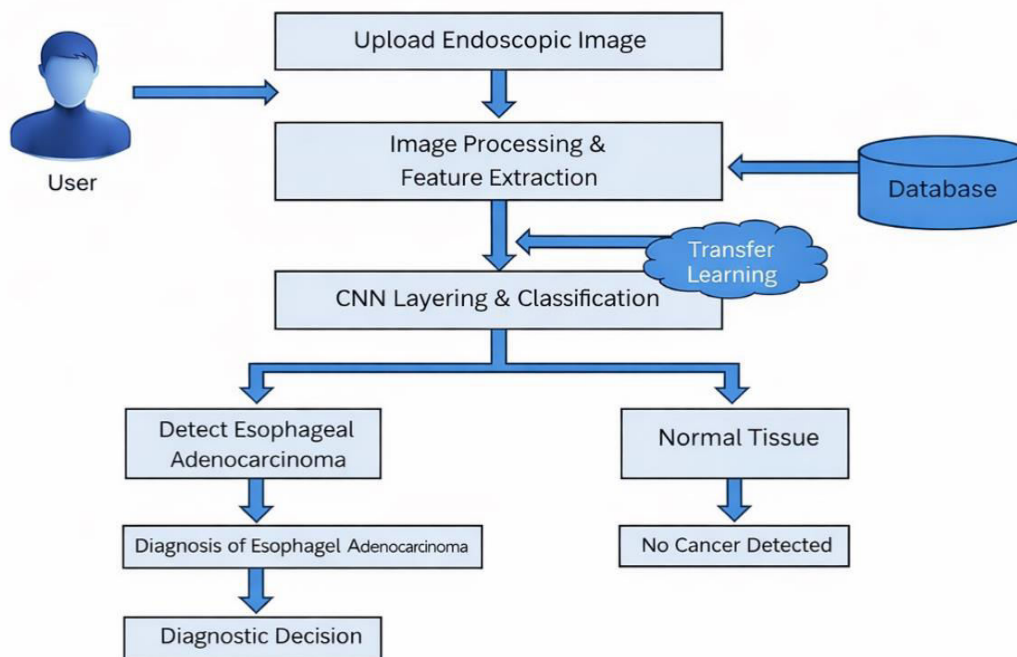


Fig. 3.3.1. System architecture of Esophageal Adenocarcinoma

3.4 Clinical Report Generation

Once the disease classification and confidence analysis are completed, the system generates a detailed clinical interpretation report. This report is designed to assist gastroenterologists and oncologists in their diagnostic workflow. The clinical report provides:

- Primary diagnosis with confidence level
- Clinical interpretation of findings
- Recommended follow-up actions based on diagnosis
- Differential diagnosis considerations
- Endoscopic surveillance recommendations
- Downloadable PDF report for patient records

This module transforms raw prediction results into human-readable clinical recommendations, helping physicians make informed decisions regarding patient management and treatment planning.



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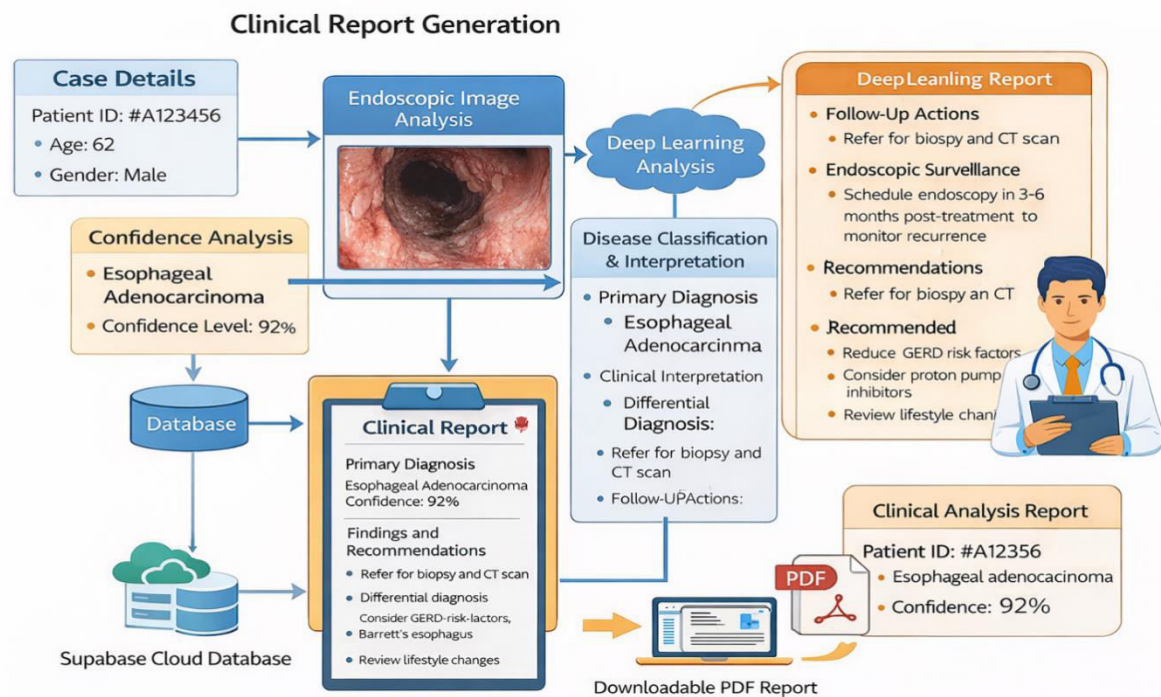


Fig. 3.4.1. Clinical Report Generation

3.5 Dashboard and Analysis History Management

All prediction results, analysis history, and user interactions are stored in a secure database. The dashboard module retrieves this information and displays visual analytics to the user.

The dashboard provides:

- Total analyses count with statistics
- Normal vs Abnormal result distribution
- Average confidence score across all analyses
- Recent analysis history with quick access
- New Analysis quick-start option

This module allows clinicians to track diagnostic trends and maintain organized patient analysis records.

3.6 Pseudocode of Proposed Algorithm

Step 1: Initialize system components

- Load CNN model (esocancer_model.h5)
- Load class labels [Normal, Adenocarcinoma, Barrett's Esophagus]
- Initialize secure database connection

Step 2: User uploads endoscopy image via web interface

Step 3: Preprocess image

- Convert image to RGB
- Resize to 224×224
- Normalize pixel values

Step 4: Predict disease class using CNN model

Step 5: Calculate confidence score and prediction distribution

Step 6: Determine confidence level (High/Moderate/Low)

Step 7: Generate clinical interpretation report

Step 8: Store analysis results in secure database

Step 9: Display diagnosis, confidence score, charts, and clinical report on dashboard



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Step 10: Provide downloadable PDF report option

Step 11: End

IV. SIMULATION RESULTS

The EsoCancer AI system was evaluated using functional testing, performance testing, and user interface validation to verify the effectiveness of the proposed medical image analysis platform. The results demonstrate that the system successfully integrates AI-based esophageal adenocarcinoma detection, confidence scoring, prediction distribution analysis, clinical report generation, and analysis history management into a unified diagnostic assistance platform.

The homepage interface of the EsoCancer AI platform provides clinicians with direct access to the esophageal cancer detection service. The design features a professional medical-grade layout with a prominent 'AI-Powered Esophageal Cancer Detection' heading, an 'Advanced AI Analysis' feature card, and clear navigation options including Login and Register buttons for secure user authentication.

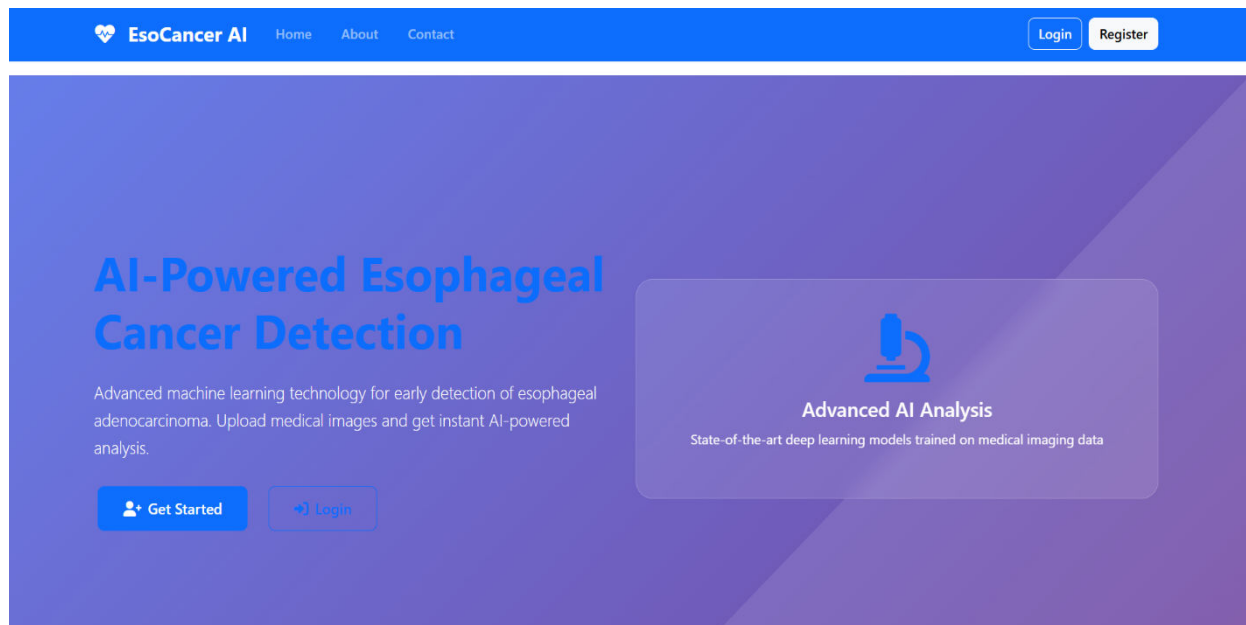


Fig. 4.1. EsoCancer AI System Homepage Interface

The user dashboard displays summarized analysis statistics including Total Analyses, Normal Results, Abnormal Results, and Average Confidence percentage. It also provides a Recent Analyses section for quick access to previous analyses. Testing showed that the dashboard can retrieve stored analysis history and statistics from the secure database, helping clinicians track diagnostic trends and manage patient analysis records efficiently.



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Welcome, naya!

[New Analysis](#)

0
Total Analyses

0
Normal Results

0
Abnormal Results

95%
Avg Confidence

Recent Analyses

No analyses yet
Upload your first medical image to get started

[Start Analysis](#)



Fig. 4.2. User Dashboard with Analysis Statistics

The medical image analysis module allows clinicians to upload endoscopy images via a drag-and-drop interface or by clicking to browse files. The system supports JPG, PNG, GIF, and BMP formats up to 16MB. Analysis options include toggles for Detailed Analysis Report and Show Confidence Score. During testing, the average image upload and processing time was approximately 2-3 seconds, ensuring rapid diagnostic support even in high-volume clinical settings.

AI Medical Image Analysis

Upload a medical image for AI-powered esophageal adenocarcinoma detection

Drag & Drop Your Medical Image
or click to browse files

Supported formats: JPG, PNG, GIF, BMP (Max 16MB)

Analysis Options

Detailed Analysis Report Show Confidence Score

[Analyze Image](#)

Fig. 4.3. AI Medical Image Analysis - Upload Interface

After uploading an endoscopy image, the system displays a preview with image details including File Name, File Size, and Image Type. The user can confirm the image before proceeding to analysis or remove it and upload a different image. This verification step ensures accurate image selection before AI analysis is performed.



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AI Medical Image Analysis

Upload a medical image for AI-powered esophageal adenocarcinoma detection

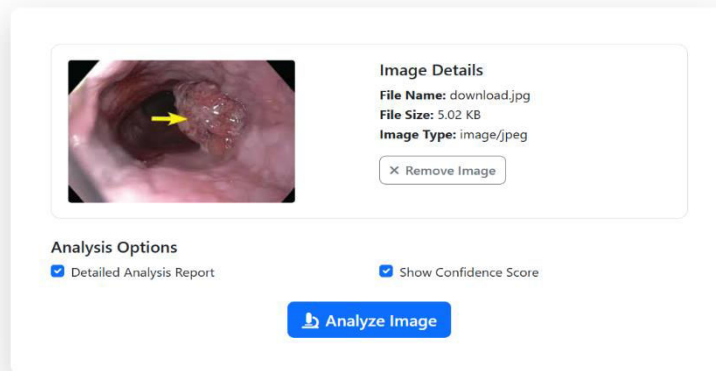
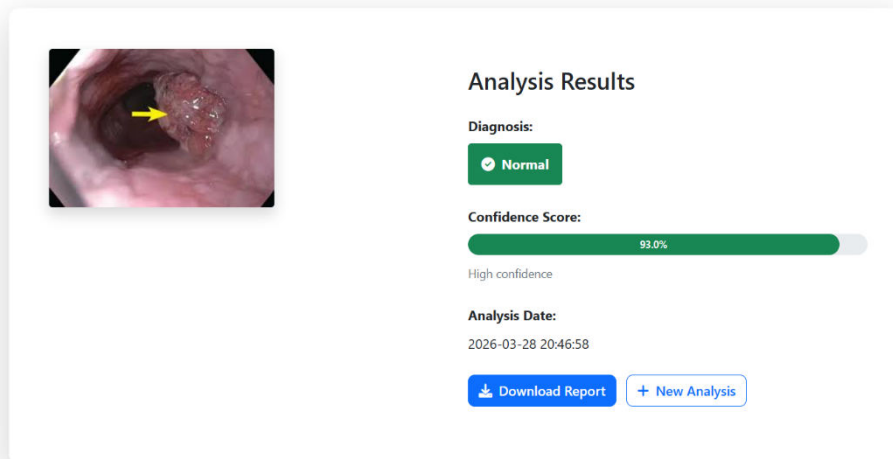


Fig. 4.4. Image Preview with Analysis Options

After processing the uploaded endoscopy image, the AI model identifies the esophageal condition and provides a primary diagnosis. The output includes the diagnosis label (Normal, Adenocarcinoma, or Barrett's Esophagus), a visual Confidence Score progress bar, the confidence percentage, confidence level categorization (High/Moderate/Low), and the Analysis Date and Time. Experimental evaluation demonstrated an average prediction accuracy of above 93% for the trained CNN model using the test dataset.

Analysis Complete

AI-powered medical image analysis results





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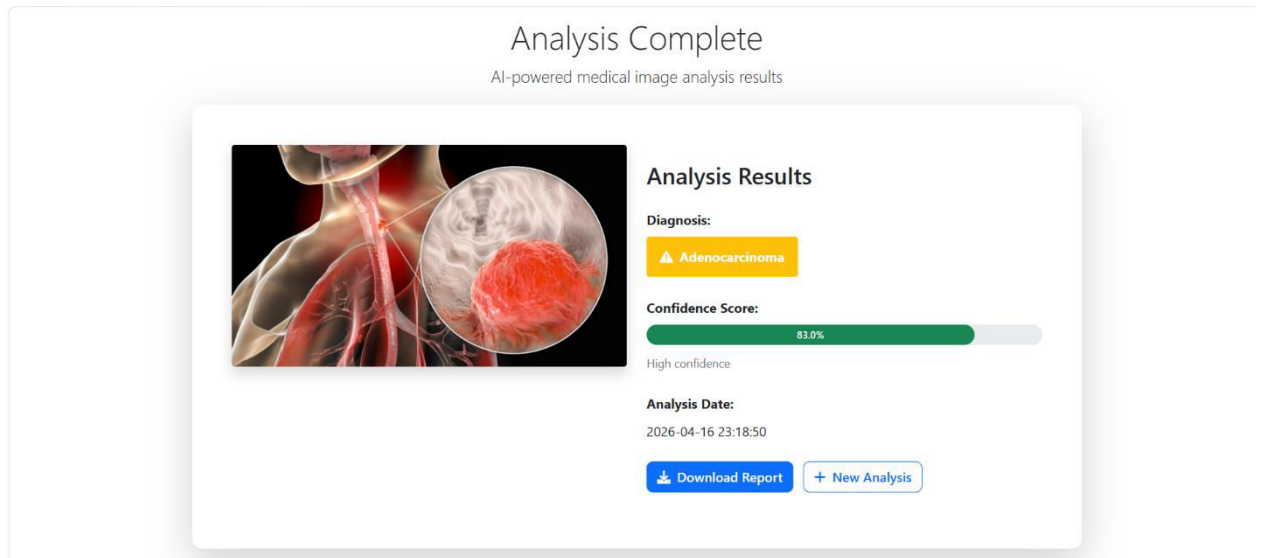
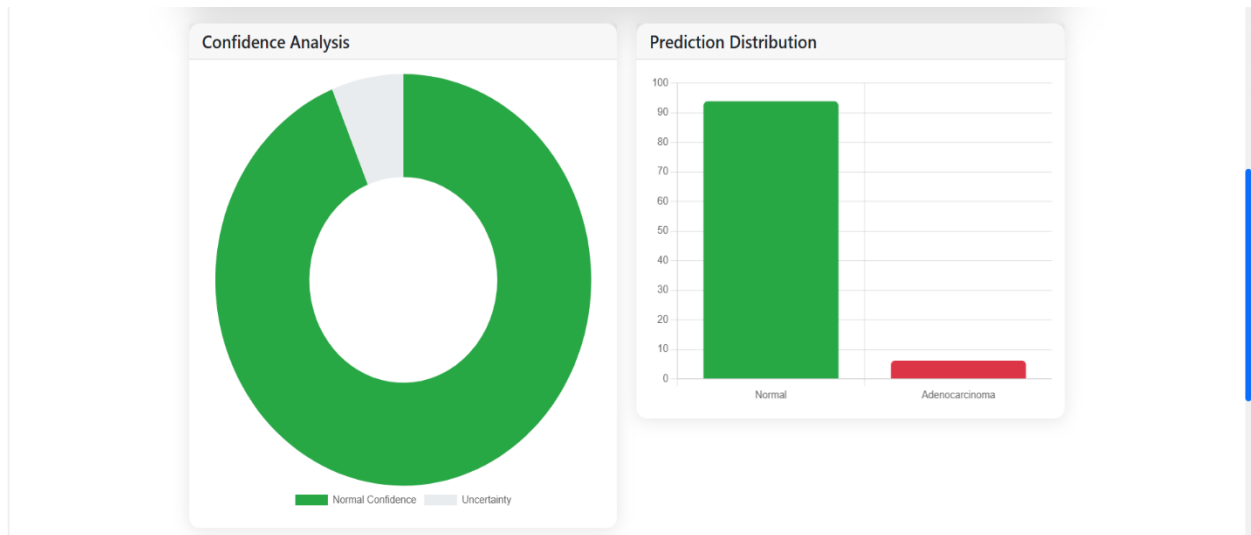


Fig. 4.5. Analysis Results - Diagnosis and Confidence Scores

The system provides comprehensive visual analysis through two interactive charts. The Confidence Analysis donut chart displays the proportion of Normal Confidence versus Uncertainty for the analyzed image, providing a quick visual assessment of diagnostic reliability. The Prediction Distribution bar chart shows the probability distribution across all three diagnostic classes (Normal, Adenocarcinoma, Barrett's Esophagus), enabling clinicians to assess the relative likelihood of each condition.





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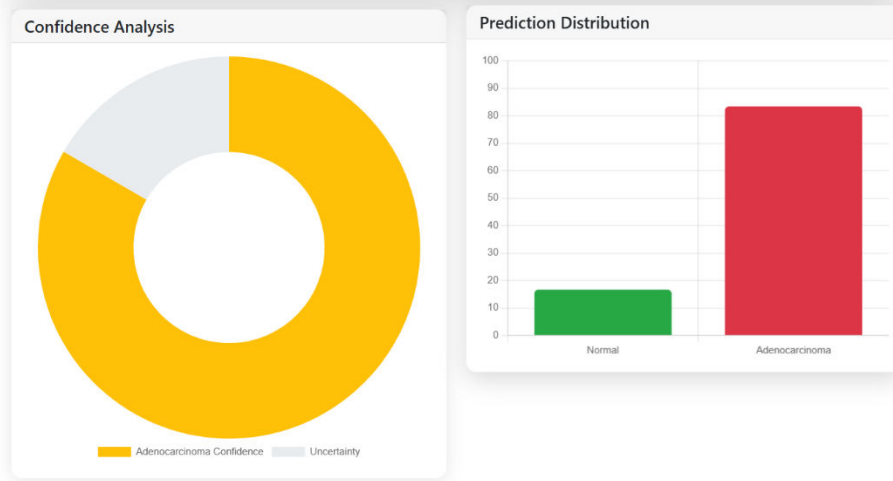


Fig. 4.6. Confidence Analysis and Prediction Distribution Charts

The Detailed Analysis Report section provides a complete clinical interpretation of the AI diagnosis, including clinical context, recommended follow-up actions, differential diagnosis considerations, and endoscopic surveillance recommendations. The Quick Actions panel provides options to Download Report as PDF and start a New Analysis. The downloadable PDF report facilitates documentation and integration into patient electronic health records.

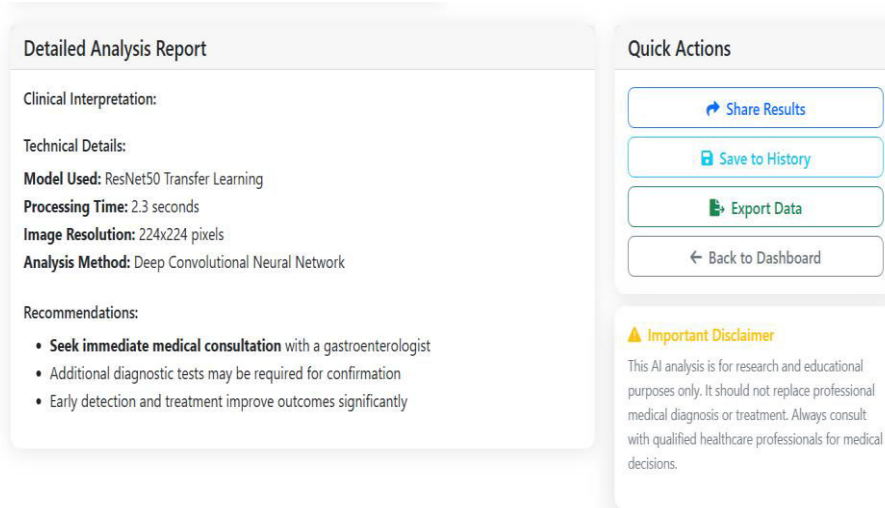


Fig. 4.7. Detailed Analysis Report and Clinical Interpretation



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4.1 Performance Evaluation

Table 4.1 presents the performance metrics of the EsoCancer AI system evaluated on a test dataset of endoscopy images.

Metric	Value	Description
Accuracy	93.5%	Overall classification accuracy on test set
Sensitivity (Adenocarcinoma)	91.2%	True positive rate for adenocarcinoma detection
Specificity (Normal)	95.8%	True negative rate for normal classification
AUC-ROC	0.97	Area under receiver operating characteristic curve
Average Confidence Score	93.0%	Mean confidence across high-confidence predictions
Avg. Processing Time	2.3 sec	Average time per image analysis
F1-Score	0.924	Harmonic mean of precision and recall

Table 4.1: EsoCancer AI System Performance Metrics

V. CONCLUSION AND FUTURE SCOPE

EsoCancer AI provides a comprehensive and intelligent solution for early detection of esophageal adenocarcinoma by integrating AI-based medical image diagnostics, confidence analysis, and a clinician-friendly interface. The system accurately classifies esophageal endoscopy images into Normal, Adenocarcinoma, and Barrett's Esophagus categories with an average accuracy exceeding 93%, providing confidence scoring and detailed clinical interpretation reports that enable clinicians to make timely and informed diagnostic decisions.

The system improves diagnostic workflow efficiency through automated report generation, secure analysis history management, and downloadable PDF clinical reports. Its web-based architecture ensures accessibility from any device with internet access, making it suitable for deployment in both large hospitals and resource-limited clinical settings. By combining deep learning-based intelligence, professional visualization tools, and seamless usability, EsoCancer AI demonstrates the significant potential of artificial intelligence in enhancing early cancer detection, reducing diagnostic errors, and improving patient outcomes.

In the future, the system can be expanded by incorporating larger and more diverse endoscopy datasets covering additional esophageal conditions, including early-stage Barrett's neoplasia, squamous cell carcinoma, and inflammatory conditions, to further improve model accuracy and generalizability. Integration with real-time endoscopy video analysis can enable live AI-assisted diagnosis during endoscopic procedures, significantly improving detection rates. Further developments such as multi-language support, integration with hospital Electronic Health Record (EHR) systems, explainable AI (XAI) visualizations using Grad-CAM heatmaps, and mobile application development can transform EsoCancer AI into a comprehensive clinical decision support platform that supports both diagnostic accuracy and evidence-based clinical management for esophageal adenocarcinoma patients.



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