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Differentiation of Benign Vs. Malignant Colorectal Polyps Using Machine Learning Techniques: A Systematic Review and Meta-Analysis

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ABSTRACT

Colorectal polyps are critical markers for colorectal cancer (CRC), and distinguishing between benign and malignant polyps is essential for early diagnosis and treatment. This systematic review and meta-analysis assess the performance of machine learning techniques in accurately differentiating benign from malignant colorectal polyps. The review examines recent research that integrates advanced technologies, including computer-aided diagnosis (CADx) systems and deep learning models, particularly convolutional neural networks (CNNs). These machine learning techniques show great promise in analyzing histopathological images, identifying subtle patterns and characteristics that may be overlooked by traditional methods. Additionally, the integration of optical coherence tomography (OCT) with CADx systems enhances tissue structure interpretation, leading to more precise diagnoses. By synthesizing data from multiple studies, this review highlights the significant advancements in CRC diagnosis and the potential for improved patient outcomes through the application of machine learning techniques.

Keywords - ***Benign, Colorectal Cancer, Colorectal Polyps, Computer-Aided Diagnosis, Convolutional Neural Networks, Deep Learning, Histopathological Images, Malignant, Optical Coherence Tomography, Systematic Review.***

1. INTRODUCTION

Because of its high rates of illness and mortality, colorectal cancer is thought to be the second most common cause of cancer-related fatalities worldwide [1]. As such, it poses a significant challenge. Colonoscopy is the most effective way to accurately locate and classify colorectal polyps within the body in order to treat this illness [1]. Precancerous polyps can be identified and removed before they become cancerous by closely examining the results of a colonoscopy, which significantly lowers the death rate from colorectal cancer. While the use of machine learning techniques to classify colorectal polyps is growing, a comprehensive analysis is still necessary to identify possible directions for further research and practical application, weigh the advantages and disadvantages of recent findings, and investigate ongoing investigations. The objective of this systematic review is to investigate in detail how ML-based methods are currently used to differentiate between benign and malignant colorectal polyps. The review also aims to explore the potential of machine learning techniques to enhance diagnostic accuracy and inform clinical judgments for colorectal cancer screening and treatment by evaluating data from several studies.

1.1 RATIONALE

The rationale for conducting this systematic review stems from the pressing need to accurately differentiate between benign and malignant colorectal polyps, a critical aspect in combating colorectal cancer (CRC), which poses a significant health burden worldwide. With CRC being a leading cause of illness and death globally, early detection becomes imperative for effective treatment and improved patient outcomes. While colonoscopy serves as a primary screening method for identifying colorectal polyps, accurately distinguishing between benign and malignant polyps during this procedure remains challenging and subjective, leading to variability in diagnostic accuracy among healthcare providers. In recent years, machine learning techniques, particularly deep learning algorithms, have emerged as promising tools to aid in the classification of colorectal polyps based on endoscopic images. Against this backdrop, this systematic review endeavours to critically assess the existing literature on machine learning approaches for discerning between benign and malignant colorectal polyps, with the aim of synthesizing evidence to inform clinical practice and guide future research endeavours.

1.2 AIM AND OBJECTIVES

The systematic review aims to do the following

1. To systematically review and analyse existing literature on machine learning techniques applied to differentiate between benign and malignant colorectal polyps.

2. To evaluate the diagnostic performance and accuracy of machine learning algorithms in distinguishing between

benign and malignant colorectal polyps based on available evidence.

3. To conduct a meta-analysis in order to systematically combine and evaluate data from the studies included, thereby improving the strength and completeness of the synthesized results.

2.0 MATERIALS AND METHOD

Following the PRISMA guideline, a thorough literature search was conducted on Scopus and Google Scholar databases covering the period from 2015 to 2024.

2.1 INCLUSION CRITERIA

- Studies focusing on the application of machine learning techniques for the differentiation of benign versus malignant colorectal polyps.
- Research articles published in peer-reviewed journals.
- Studies involving human participants or human-derived samples.
- Articles written in English.
- Studies reporting outcomes related to the accuracy, sensitivity, specificity, or diagnostic performance of machine learning algorithms in colorectal polyp classification.
- Research conducted using various imaging modalities, including but not limited to colonoscopy, optical coherence tomography (OCT), and digital pathology.

2.2 EXCLUSION CRITERIA

- Studies not relevant to the differentiation of benign versus malignant colorectal polyps.
- Conference abstracts, letters, editorials, commentaries, and opinion pieces.
- Studies focusing solely on animal models or in vitro experiments.

Articles not available in full-text format.

- Research conducted in languages other than English.
- Studies with insufficient data or methodology details to assess the application of machine learning techniques.
- Duplicate publications or overlapping datasets from the same research group.

2.3 INFORMATION SOURCES

The databases used for this review were SCOPUS, Google Scholar and PUBMED.

2.4 SEARCH QUERY: The articles in SCOPUS where found by entering the keywords below into the search bar.

TITLE-ABS-KEY ((differentiation OR classif*) AND (benign) AND (malignant) AND (("colorectal polyps" OR "colorectal cancer" OR "colorectal carcinoma" OR "colorectal tumor")) AND ("MACHINE LEARNING" OR ml OR "ARTIFICIAL INTELLIGENCE" OR ai OR "DEEP LEARNING" OR "NEURAL NETWORK") AND (techniques OR method* OR algorithm OR approach OR style OR process)) AND (LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "HEAL") OR LIMIT-TO (SUBJAREA , "BIOC") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))

25 DOCUMENTS FOUND

GOOGLE SCHOLAR: 83 DOCUMENTS.

TOTAL DOCUMENTS: 108.

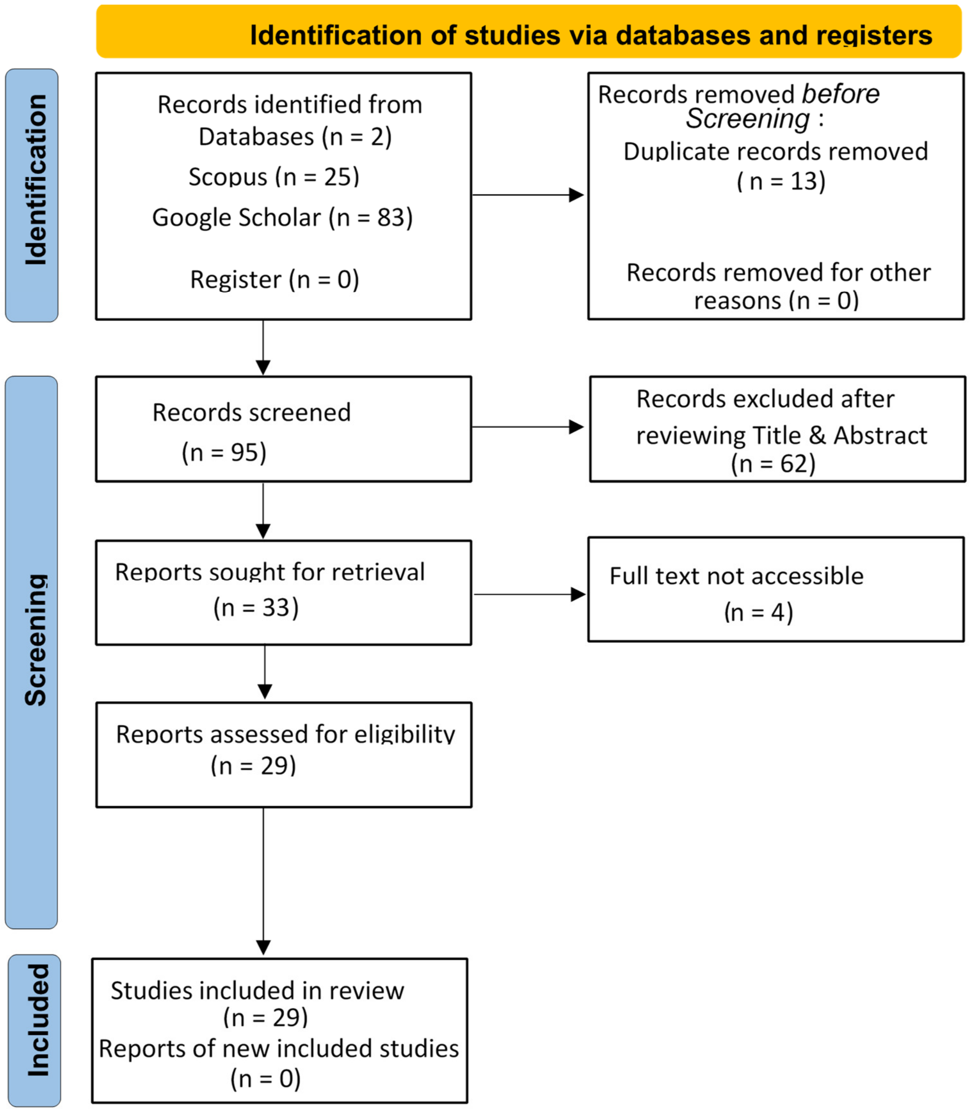

Fig 1. Flow Diagram showing screened studies.

2.5 DATA EXTRACTION

Data extraction was meticulously undertaken by a single reviewer to consolidate advancements in machine learning methods for distinguishing between benign and malignant colorectal polyps. Following a systematic approach, pertinent data was gathered from chosen studies, emphasizing study attributes, methodologies, obstacles, and suggestions for enhancement.

Fig 1. shows the screening phase of the review The primary aim of this thorough extraction process was to offer a comprehensive understanding of how machine learning techniques are utilized in the differentiation of colorectal polyps.

During the review, any discrepancies were diligently resolved through careful examination and reference to relevant literature.

2.6 RISK OF BIAS

A rigorous screening process was used for the systematic review in order to evaluate any potential biases. Studies that matched the research focus on utilizing machine learning approaches to classify colorectal polyps were assessed based on the defined eligibility criteria. By identifying and reducing any biases in the chosen studies, this critical evaluation attempted to protect the validity and reliability of the research findings.

3.0 RESULTS

Numerous research focusing on the identification, categorization, and diagnosis of colorectal cancer (CRC) using different technologies and approaches were found through the search. This research looked at the use of traditional machine learning techniques, optical coherence tomography (OCT), computer-aided diagnosis (CADx) systems, and deep learning methods. The results showed that these methods, with their promising sensitivity and specificity values, were useful in correctly identifying colorectal polyps as benign or malignant. The research also showed how cutting-edge imaging modalities, including OCT, might offer on-the-spot, in-situ diagnostics in real time during colonoscopy procedures. All things considered, the search indicated an increasing interest in using technology to further CRC early detection and care, with an emphasis on improving patient outcomes and diagnostic accuracy.

Table 1. Summary of Included Studies.

S/N	AUTHOR	TITLE	SUMMARY
1	C. Ho *et al 2022. [1]*	A promising deep learning-assistive algorithm for histopathological screening of colorectal cancer.	This paper describes an innovative artificial intelligence (AI) deep learning system designed to screen for colorectal polyps in tissue samples, with the goal of alleviating the growing workload in histopathology labs caused by the increasing number of colonoscopy procedures. The model uses a unique combination approach that consists of a ResNet-101 for glandular structure feature extraction and a Faster area Based Convolutional Neural Network for area identification. The findings show a robust performance, as evidenced by an area under the receiver-operator characteristic curve (AUC) of 0.917, and a high sensitivity (97.4%) in identifying markers of dysplasia and cancer. By identifying dysplastic and malignant glands, our composite AI model offers pathologists a useful tool that could improve workflow efficiency and lessen diagnostic burdens. ongoing improvement via training and calibration is expected to further improve its accuracy in classifying colorectal specimens by risk level [1].
2	S. Byeon, J. Park, Y. A. Cho, and B. J. Cho, (2022). [2]	Automated histological classification for digital pathology images of colonoscopy specimen via deep learning.	The study explores the automatic classification of digital pathology images of colon lesions obtained from specimens associated with colonoscopies using deep learning models. Six distinct forms of colorectal lesions were represented by the extensive collection of histological slides that the researchers gathered: hyperplastic polyp, tubular adenoma, conventional serrated adenoma, sessile serrated adenoma, and non-specific lesions. After that, they worked through digital copies of these slides, fine-tuning and closely scrutinizing DenseNet-161 and EfficientNet-B7, two convolutional neural networks that had already been trained. Additionally, the models demonstrated strong performance on the receiver operating characteristic curve values for every class, with tubular adenoma and adenocarcinoma receiving particular attention. Interestingly, saliency maps were able to identify important regions in the digital images, with a focus on epithelial lesions. These results suggest that deep learning models have potential to assist in diagnosing colonoscopy-related specimens, promising better accuracy and efficiency in classifying colorectal lesions [2].
3	C. Lo, Y. Yeh, J. Tang, and C. Chang. (2022). [3].	Rapid Polyp Classification in Colonoscopy Using Textural and Convolutional Features	This research presents a CAD system aimed at categorizing polyp types through colonoscopy images, providing gastroenterologists with accurate and productive evaluations. The study demonstrates that AlexNet trained from scratch outperforms other methods by achieving 96.4% accuracy using deep convolutional neural networks like Inception-V3, ResNet-101, and DenseNet-201, through extracting textural features. Although texture features are more easily processed and understood, DCNNs provide greater accuracy but require more computational power and data. The research indicates that using DCNNs for polyp classification can greatly enhance

			accuracy, helping with quick treatment planning during colonoscopy procedures and possibly expanding to predicting tissue malignancy and directing treatment in inflammatory bowel diseases, thereby progressing the diagnosis and management of gastrointestinal pathology [3].
4	S. Grosu *et al*. 2021. [4].	Machine Learning – based Differentiation of Benign and Premalignant Colorectal Polyps Detected with CT Colonography in an Asymptomatic Screening Population	The research focuses on the difficulty of clearly distinguishing between benign and premalignant colorectal polyps using CT colonography (CTC). A proof-of-concept study examined using machine learning to distinguish between polyps in CTC data. The results showed strong performance with an AUC of 0.91, especially for small polyps measuring 6–9 mm. Validation from an external source in a broad multicenter study substantiated the method's strength with different scanner types and imaging protocols. The method used in the study involved using standardized radiomics features and resampling CT colonography scans to enhance reproducibility and reduce variability in image acquisition. In spite of small sample size and potential selection bias, the results indicate the possible clinical significance of incorporating machine learning-assisted image analysis in CTC-based colorectal cancer screening, allowing for more accurate patient selection for additional diagnostic procedures. Additional studies with bigger groups are needed to confirm these results and evaluate diagnostic accuracy more thoroughly [4].
5	F. Ponzio, E. Macii, E. Ficarra, and S. Di Cataldo, (2018) [5]. .	Colorectal Cancer Classification using Deep Convolutional Networks An Experimental Study.	The research concentrates on enhancing the categorization of colorectal tissue samples, which is vital for detecting colorectal cancer early, by introducing a deep learning approach using Convolutional Neural Networks (CNNs). Automated analysis encounters challenges with image variability, despite the unreliability and time-consuming nature of traditional visual assessment. Training the CNN completely results in around 90% accuracy in classification, yet it requires a lot of computational resources. Therefore, the research investigates methods of transfer learning, using CNN models that were pre-trained on ImageNet, resulting in significantly higher performance than fully trained CNNs, reaching an accuracy of around 96%. The findings show that transfer learning is effective in improving classification accuracy and decreasing training time. Future endeavors seek to broaden the classification issue to encompass additional tissue categories and create a thorough framework for analysing colorectal histology using CNNs [5].
6	*Y. Tian et al.(2021). [6].*	Detecting, Localising and Classifying Polyps from Colonoscopy Videos using Deep Learning	The article presents a method for identifying, pinpointing, and categorizing polyps in colonoscopy videos automatically, tackling issues like unclear images and disturbances including faeces and water sprays. The system employs a method of few-shot anomaly detection to discard unimportant frames prior to polyp detection, resulting in top-notch performance. An efficient approach for detecting and categorizing polyps in one step shows better results than manual detection techniques. Findings show that improving confidence calibration and uncertainty estimation can boost classification accuracy, encouraging the creation of more understandable classification techniques. Future efforts will focus on enhancing accuracy in localization, filling in classification gaps, reducing running time, and investigating the potential for generalization to new

			domains using domain adaptation and generalization techniques [6].
7	P. Sharma, K. Bora, K. Kasugai, and B. K. Balabantaray. (2020). [7].	Two Stage Classification with CNN for Colorectal Cancer Detection	The paper presents a method for detecting colorectal cancer from colonoscopy videos using a two-stage classification approach, which is crucial in medical image processing. In the first stage, frames are extracted and important ones with polyps are identified, while in the second stage, these results are combined to classify frames as neoplastic or non-neoplastic. Different deep learning models like vgg16, vgg19, inception v3, among others, are tested, and the fine-tuned vgg19 achieves the highest accuracy of 95.75%. The success of the vgg19 model is attributed to transfer learning from the imagenet dataset. This research offers valuable insights into automated colorectal cancer detection, potentially aiding medical practitioners with precise 3d location information for identified polyps [7].
8	M. S. Hossain et al. (2023), [8].	DeepPoly: Deep Learning-Based Polyps Segmentation and Classification for Autonomous Colonoscopy Examination	The article discusses the important topic of identifying colorectal cancer (CRC) by suggesting a self-governing screening technique that combines DoubleU-Net for polyp segmentation and Vision Transformer (ViT) for risk evaluation. Automated solutions are needed to address the time-consuming and error-prone nature of manual colonoscopy examinations for polyp detection. The proposed method outperforms state-of-the-art methods with mean dice coefficients of 0.834 and 0.956 for polyp segmentation on the Endotech challenge and Kvasir-SEG dataset, respectively. Additionally, it achieves a test accuracy of 99% in accurately segmenting polyps and identifying them as hyperplastic or adenomatous. The study also discusses the potential use of automated colonoscopy tests to improve polyp detection and general health of the colon, paving the way for their broad usage in healthcare facilities and future developments in the identification of polyps from a variety of endoscopic images [8].
9	H. K. Kim et al. (2024). [9].	Artificial-Intelligence-Assisted Detection of Metastatic Colorectal Cancer Cells in Ascitic Fluid.	The aim of the research is to apply artificial intelligence (AI) to ascites cytology in order to increase its accuracy in identifying metastatic colorectal cancer (CRC). For peritoneal metastatic cancer, conventional biopsy results often lack sufficient sensitivity and specificity, leading to notable variations in interpretations across observers. The new artificial intelligence (AI) system DoubleU-Net achieved remarkable results with an accuracy of 93.74%, sensitivity of 87.76%, and specificity of 99.75% when identifying benign and malignant cells in ascitic fluid patch images by using a potent convolutional neural network (CNN) that was trained on a substantial dataset. When employing the recommended AI method, the DoubleU-Net algorithm significantly increased pathologists' diagnosis accuracy, increasing it from 86.8% to 90.5%, and sensitivity, increasing it from 73.3% to 79.3%. This demonstrates how it can help pathologists of all skill levels diagnose metastatic CRC cells in ascites [9].
10	S. Tanwar, P. Goel, P. Johri, and M. J. Divan. (2020). [10].	Classification of Benign and Malignant Colorectal Polyps using Pit Pattern Classification.	The paper highlights the critical need for prompt detection of Colorectal Cancer. To help with early intervention and treatment, it suggests using deep learning to classify benign and malignant tumors. The model acquired an accuracy of 87 percent in differentiating between benign and malignant tumors by training a deep convolutional neural network (CNN) on a private dataset. The study shows how

			deep learning methods can be useful in polyp segmentation and shows how effective they are in promptly detecting colorectal cancer. Deep learning techniques for automated colorectal cancer diagnosis have demonstrated their resilience, as demonstrated by the encouraging outcomes of the incremental approach that was used, which included feature extraction and fine-tuning. These developments appear to have the potential to dramatically lower the rates of CRC-related misdiagnosis and death. Subsequent investigations could focus on developing the model into an instantaneous system to analyze video data from colonoscopies. This would augment the system's capacity for automated risk evaluation and enhance its outcomes by incorporating more sophisticated techniques and larger datasets [10].
11	P. Wesp et al. (2022). [11].	Deep learning in CT colonography : differentiating premalignant from benign colorectal polyps.	The research centers on colorectal cancer (CRC), a primary cause of cancer-related fatalities in the United States, anticipated to result in 52,580 deaths in 2023. Colonoscopy is the usual approach for CRC screening and treatment, and it successfully detects precancerous polyps for timely removal, ultimately lowering mortality rates. Nevertheless, identifying polyps manually during colonoscopy is a time-consuming, boring, and error-prone task. Current automated techniques for polyp segmentation do not possess precision and fail to assess the potential dangers linked to identified polyps. In order to overcome these constraints, the research suggests a self-governing CRC screening method. DoubleU-Net is used for identifying polyps, while Vision Transformer (ViT) is employed for categorizing risk levels. The method suggested shows substantial advancements in accuracy for polyp segmentation, surpassing current cutting-edge techniques on both the Endotech challenge and Kvasir-SEG dataset. Furthermore, the approach has shown high precision in differentiating between hyperplastic and adenomatous polyps, offering a potential remedy for precise and effective colorectal cancer screening [11].
12	P. Sasmal, M. K. Bhuyan, and S. Member. (2021). [12].	Colonoscopic Polyp Classification Using Local Shape and Texture Features.	The paper proposes a method for classifying colonic polyps, providing a virtual biopsy to assess malignancy stage. It utilizes geometry, texture, and color cues of polyps, characterizing their shape with pyramid histogram of oriented gradient (PHOG) features and surface texture with a fractal weighted local binary pattern (FWLBP) descriptor, which is robust to affine transformations and illumination variations encountered during endoscopy. Feature fusion is optimized using a fuzzy entropy-based algorithm, and classification is performed using kernel-based support vector machines (SVM) and RUSBoosted tree. Experimental results on two databases demonstrate the effectiveness of the proposed method, achieving polyp classification accuracies of 90.12% and 84.1%, with AUC values of 0.91 and 0.92, respectively [12].
13	H. Cai et al. (2023). [13].	MIST: multiple instance learning network based on Swin Transformer for whole slide image classification of colorectal adenomas.	The paper addresses the need to accurately classify colorectal adenomas, crucial for early screening of colorectal cancer, which originates from these lesions. Existing deep learning pathology studies require manual annotation, which is time-consuming. The proposed approach, MIST (Multiple Instance learning network based on the Swin Transformer), classifies colorectal adenoma whole slide images (WSIs) with only slide-level labels. MIST utilizes the Swin Transformer for feature extraction and a dual-

			stream multiple instance learning network for slide classification. Trained and validated on 666 WSIs, MIST achieved an accuracy of 0.784 in external validation, outperforming existing methods and approaching local pathologists' accuracy. The interpretability analysis showed MIST's lesion area detection aligns with pathologists' interests. MIST offers a low-burden, interpretable, and effective solution for colorectal cancer screening, potentially reducing CRC mortality by aiding clinicians in decision-making [13].
14	S. Zhang et al. (2019). [14].	An investigation of CNN models for differentiating malignant from benign lesions using small pathologically proven datasets.	This research focuses on the challenge of effectively using small datasets for cancer detection via deep learning models, particularly convolutional neural networks (CNNs). With the difficulty of collecting large volumes of medical images with pathological information, the study explores two CNN models to differentiate between malignant and benign lesions in two small datasets: colorectal polyps and lung nodules. Despite the limited dataset sizes (less than 70 subjects), the proposed CNN models successfully distinguish malignancy, achieving average AUCs of 0.86 for colorectal polyps and 0.71 for pulmonary nodules. Additionally, incorporating additional image features, such as the local binary pattern of the lesions, significantly improves classification performance. The voxel-level CNN model performs better with small and unbalanced datasets, demonstrating promising results for cancer detection in medical imaging despite limited data availability [14].
15	M. M. Attia, N. F. F. Areed, H. M. Amer, and M. El-Seddek. (2024). [15].	A deep learning framework for accurate diagnosis of colorectal cancer using histological images	The article discusses the significance of early detection of colorectal cancer (CRC) and explores the use of deep learning techniques, specifically convolutional neural networks (CNN), for its classification into benign and malignant forms. After preprocessing the image dataset, the study evaluates multiple CNN models, including ResNet-18, ResNet-50, GoogLeNet, and MobileNetV2, using different subsets of testing data. Various network architectural techniques are compared, and the performance of algorithms is assessed based on accuracy, sensitivity, specificity, precision, F1-score, and area under the receiver operating characteristic (ROC) curve (AUC). The results indicate that deep learning approaches exhibit high efficacy in accurately diagnosing colorectal cancer, suggesting their significant potential for advancing medical research in this field [15].
16	O. Bardhi, D. Sierra-Sosa, B. Garcia-Zapirain, and L. Bujanda. (2021). [16].	Deep learning models for colorectal polyps.	The article addresses the significance of detecting colon polyps early to prevent late diagnosis of colorectal cancer, a leading cause of cancer-related deaths globally. It summarizes current research on colon polyp detection, localization, and classification and emphasizes the growing application of deep learning algorithms in this area. The authors compare the accuracy of these studies with their own results obtained from training and testing three independent datasets using a convolutional neural network and auto-encoder model. They report achieving accuracies of 0.937, 0.951, and 0.967 for the respective datasets, indicating slight improvements over existing algorithms. This study highlights the potential of deep learning methods to improve colon polyp identification and categorization, advancing the field of colorectal cancer diagnosis [16].

17	T.-J. Su, F.-C. Lee, C.-K. Sun, F.-X. Ke, S.-M. Wang, and M.-C. Huang. (2022). [17].	The Application of Convolutional Neural Network Combined with Fuzzy Algorithm in Colorectal Endoscopy for Tumor Assessment.	This study utilizes convolutional neural networks (CNNs) to evaluate tumor risk in the colon through colonoscopy images. Stress and alterations in lifestyle lead to higher risk factors like aging and an unhealthy body mass index (BMI), which are associated with a high incidence and death rate of colorectal cancer. By classifying endoscopic images into healthy, benign tumor, and malignant tumor categories, the CNN model, when combined with patient data, accurately assesses cancer risk using a fuzzy algorithm. The method achieves a tumor profile accuracy of 81.6 percent, surpassing recent studies in colorectal cancer tumor analysis. This method may help doctors diagnose colorectal cancer and choose the best course of treatment [17].
18	A. Akilandeswari et al. (2022). [18].	Automatic Detection and Segmentation of Colorectal Cancer with Deep Residual Convolutional Neural Network.	This article introduces a CAD system designed to automatically detect colorectal tumors early on using CT scans of the colon. The study is focused on accurately identifying tumor cells in the intricate digestive tract using the DICOM format to ensure the best possible treatment. The suggested method involves two stages: segmentation and lesion extraction. The segmentation of the colon and polyps from CT images is achieved using a deep convolutional neural network (DCNN) built on residual networks. Adding residual stack blocks to the hidden layers helps the network preserve important spatial information needed for accurate segmentation. The ResNet-powered CNN efficiently separates colorectal tumors, reaching impressive dice scores (with an average of 91.57%), sensitivity (98.28), specificity (98.68), and accuracy (98.82). The results show that the suggested network model is successful in segmenting and categorizing colorectal tumors, showing potential for early detection and diagnosis of cancer [18].
19	C. L. Saratxaga et al. (2021). [19].	Characterization of optical coherence tomography images for colon lesion differentiation under deep learning.	This research introduces a method for automatically categorizing (benign versus malignant) optical coherence tomography (OCT) images of colon lesions, with the goal of improving early diagnosis and detection. Using a collection of over 94,000 images of healthy, hyperplastic, and neoplastic colonic samples from mice (rats), the research utilizes a deep learning model that has been trained on a data augmentation approach. Findings demonstrate encouraging levels of sensitivity and specificity, with sensitivity varying between 0.9695 ± 0.0141 to 0.9821 ± 0.0197 and specificity from 0.7865 ± 0.205 to 0.8094 ± 0.1524 across various data partitions. These results indicate that the suggested approach has the capability for automatic characterization of colon polyps and potential for future development of optical biopsy methods [19].
20	M. I. Hasan, M. S. Ali, M. H. Rahman, and M. K. Islam. (2022). [20].	Automated Detection and Characterization of Colon Cancer with Deep Convolutional Neural Networks.	Using deep convolutional neural network (DCNN) models and preprocessing methods on digital histopathology images, this study attempted to create a system for identifying and categorizing colon adenocarcinomas. With a maximum accuracy of 99.80 percent in the analysis of cancer tissues, the suggested structure demonstrated promising results. This indicates that colon lesions can be accurately classified as benign or malignant using the DCNN model and preprocessing methods. The study highlights the potential of putting this strategy into practice to create an automated and trustworthy system for identifying different types of colon cancer, which could aid medical professionals greatly in their

			diagnosis and treatment choices. The development of computer-aided diagnosis (CAD) systems to help with preprocessing colonoscopic images for a more precise diagnosis of colon cancer may also be made possible by the successful deployment of such systems [20].
21	E. Terradillos et al. (2021). [21].	Analysis on the Characterization of Multiphoton Microscopy Images for Malignant Neoplastic Colon Lesion Detection under Deep Learning Methods.	The paper focuses on utilizing multiphoton microscopy (MPM) technology and deep learning techniques to identify malignant neoplastic colon lesions without the need for histopathological staining. Since colorectal cancer is a significant global health concern, early detection is critical to improving survival rates. The authors introduced a simple MPM dataset containing images from 42 patients, trained a convolutional neural network on the dataset, and applied a spatially coherent prediction scheme for performance enhancement. The results showed a sensitivity of 0.8228 ± 0.1575 and a specificity of 0.9114 ± 0.0814 in detecting malignant neoplastic lesions. The researchers validated the approach to estimate the CNN's self-confidence in its predictions, resulting in a mean sensitivity of 0.8697 and a mean specificity of 0.9524, with a portion of images classified as uncertain [21].
22	P. Kainz, M. Pfeiffer, and M. Urschler. (2017). [22].	Segmentation and classification of colon glands with deep convolutional neural networks and total variation regularization.	The study presents a new method based on deep neural networks for accurately identifying and categorizing glands in tissue samples obtained from both benign and malignant colorectal cancer cases.. Developed for the GlaS@MICCAI2015 colon gland segmentation challenge, the approach utilizes two distinct deep convolutional neural networks (CNN) for pixel-wise classification of Hematoxylin-Eosin stained images. The first classifier distinguishes glands from the background, while the second identifies gland-separating structures. A figure-ground segmentation based on weighted total variation is then applied to produce the final segmentation result by refining the CNN predictions. The study presents both quantitative and qualitative segmentation results on the Warwick-QU colon adenocarcinoma dataset, demonstrating a tissue classification accuracy of 98% and 95% on two test sets. The findings highlight the potential of deep learning approaches in biomedical image analysis, offering highly accurate and reproducible results that could enhance the quality and efficiency of medical diagnoses [22].
23	X. Sun et al. (2021). [23].	Colorectal Polyp Detection in Real-world Scenario: Design and Experiment Study.	Colorectal polyps are abnormal tissues growing on the intima of the colon or rectum with a high risk of developing into colorectal cancer, the third leading cause of cancer death worldwide. Early detection and removal of colon polyps via colonoscopy have proved to be an effective approach to prevent colorectal cancer. Recently, various CNN-based computer-aided systems have been developed to help physicians detect polyps. However, these systems do not perform well in real-world colonoscopy operations due to the significant difference between images in a real colonoscopy and those in the public datasets. Unlike the well-chosen clear images with obvious polyps in the public datasets, images from a colonoscopy are often blurry and contain various artifacts such as fluid, debris, bubbles, reflection, specularity, contrast, saturation, and medical instruments, with a wide variety of polyps of different sizes, shapes, and textures. All these factors pose a significant challenge

			to effective polyp detection in a colonoscopy. To this end, we collect a private dataset that contains 7,313 images from 224 complete colonoscopy procedures. This dataset represents realistic operation scenarios and thus can be used to better train the models and evaluate a system's performance in practice. We propose an integrated system architecture to address the unique challenges for polyp detection. Extensive experiments results show that our system can effectively detect polyps in a colonoscopy with excellent performance in real time [23].
24	N. Dehghani et al. (2022). [24].	Robust Colorectal Polyp Characterization Using a Hybrid Bayesian Neural Network.	The article explores the importance of precisely adjusted Computer-Aided Diagnosis (CADx) systems in relation to the identification of colorectal polyps (CRPs) in colonoscopy procedures. Although CADx systems show potential in improving optical diagnostic accuracy, existing deep neural network models frequently lack dependable calibration, leading to overconfident predictions. The research paper presents a computer-aided diagnosis (CADx) system that combines Bayesian variational inference and a neural network to address this problem. Experiments show that this method effectively measures calibration confidence and model uncertainty while maintaining a high degree of classification accuracy. The application of Bayesian variational inference-based technique reduces the Expected Calibration Error (ECE) by 9.14% and 24.65% when compared to uncalibrated and postprocessed calibrated deterministic networks, respectively. This emphasizes improved accuracy when determining confidence intervals for describing colorectal polyps seen after colonoscopy [24].
25	R. Fonollà et al. (2020). [25].	A CNN CADx system for multimodal classification of colorectal polyps combining WL, BLI, and LCI modalities.	The goal of this study is to improve the classification accuracy of colorectal polyps, which are important markers of colorectal cancer (CRC), by applying modern imaging techniques such as Linked Color Imaging and Blue Laser Imaging (BLI). There is still a significant misclassification rate for pre-malignant polyps even with the Blue Laser Imaging Adenoma Serrated International Classification (BASIC) system in place to help differentiate between benign and pre-malignant polyps. The study recommends the use of a computer-aided diagnosis (CADx) system that combines information from several cutting-edge imaging techniques in order to address this problem. The system achieves a remarkable area under the curve (AUC) of 0.97, outperforming the standard clinical classification models used by endoscopists, thanks to its six widely used Convolutional Neural Network (CNN) designs. Together with visual explanatory features, the CADx system offers a probability score derived from White Light, Blue Laser Imaging, and Linked Color Imaging, providing a comprehensive approach to automatic polyp malignancy classification. By removing the need for expensive and time-consuming histological evaluations, this advancement may eventually increase patient safety [25].
26	M. Ragab, K. Eljaaly, M. F. S. Sabir, E. B. Ashary, S. M. Abo-Dahab, and E. M. Khalil. (2022). [26].	Optimized Deep Learning Model for Colorectal Cancer Detection and Classification Model.	This study delves into the creation of an advanced deep learning model, named IDL-CCDC, with the aim of diagnosing and categorizing colorectal cancer (CC). The integration of computer vision and deep learning models in healthcare decision-making is gaining traction, driven by the rapid advancements in medical imaging and the imperative to detect CC at early stages. Unlike previous approaches relying on

			text features or conventional machine learning, the innovative IDL-CCDC method combines fuzzy filtering for noise reduction with an EfficientNet model leveraging Water Wave Optimization (WWO) for feature extraction. Additionally, it employs a variational autoencoder (VAE) based on Chaotic Glowworm Swarm Optimization (CGSO) to classify CC into benign and malignant categories. Enhancing overall classification accuracy is the primary objective of implementing the CGSO and WWO algorithms. The effectiveness of the IDL-CCDC technique is validated using the Warwick-QU dataset, achieving an impressive accuracy of 0.969, thereby showcasing its superiority over recent methods in the detection and classification of CC [26].
27	D. Sarwinda, R. H. Paradisa, A. Bustamam, and P. Anggia. (2021). [27].	Deep Learning in Image Classification using Residual Network (ResNet) Variants for Detection of Colorectal Cancer.	The use of deep learning, more especially the ResNet architecture, for picture categorization-based colorectal cancer identification is investigated in this work. The researchers trained the ResNet-18 and ResNet-50 models using pictures of colon glands in an attempt to differentiate between benign and malignant colorectal cancer. The models' performance was assessed using three different testing datasets, each of which represented a different proportion of the entire dataset. The results showed that ResNet-50 performed better than ResNet-18 in terms of accuracy, sensitivity, and specificity across the three testing datasets. The test datasets with a 25 percent and 20 percent weight performed the best, with classification accuracy above 80%, sensitivity reaching 87%, and specificity exceeding 83%. In the examination of biomedical pictures, this study highlights the reliability and consistency of deep learning techniques, particularly in the context of colorectal cancer detection [27].
28	C. Saratxaga, J. Bote, J. Ortega-Moran. (2021). [28].	Characterization of optical coherence tomography images for colon lesion differentiation under deep learning.	In this work, the potential of optical coherence tomography (OCT) as a method for enhanced and early detection of colon abnormalities is examined. An analysis was conducted on a dataset that included more than 94,000 photos of normal, hyperplastic, and neoplastic rat colonic samples. A deep learning algorithm and a data augmentation method are used to automatically classify OCT images as benign or malignant. Results from the model's evaluation and training on six distinct data divisions were statistically significant. The research evaluated C-scan volumes in addition to the sensitivity and specificity of individual B-scan images. Ranges for the sensitivity and specificity were 0.7865 (±0.205) to 0.8094 (±0.1524) and 0.9695 (±0.0141) to 0.9821 (±0.0197), respectively. The results of the study indicate that the deep learning-based method that has been proposed has a lot of potential for automatically classifying colon polyps. This opens up opportunities for growth in the field of optical biopsy [28].
29	R. Doğan, B. Yilmaz. (2021). [29].	Comparison of deep learning and conventional machine learning methods for classification of colon polyp types.	With the use of colonoscopy images, this study attempts to create a computer-aided diagnosis system that can identify different types of polyps without requiring a tissue biopsy. A pair of methodologies were formulated: the first relied on traditional machine learning (ML) and employed random forests with features derived from gradient histograms descriptors. The other employed convolutional neural networks (CNNs) that were trained on colonoscopy images. The effectiveness of these methods was assessed for two categories (serrated versus adenoma). hyperplastic), as well as three categories

			(adenoma vs. hyperplastic as opposed to. narrow band and white light imaging modalities in their serrated) classifications. The conventional machine learning approach performed better than the basic CNN approach in two-category classification, outperforming all seven doctors with nearly 95% accuracy in white-light imaging. The feasibility of using machine learning or deep learning-based approaches for automatic classification of colon types on colonoscopy images was demonstrated by the simple CNN architecture, which outperformed both the doctors and conventional ML approaches for three-category classification [29].

3.1 FINDINGS

Table 1. shows that the systematic evaluation of 29 studies found that convolutional neural networks (CNNs) in particular have the potential to be an accurate tool for identifying colorectal cancer (CRC) and differentiating between non-cancerous and malignant tumours. Particularly, research on the use of the state-of-the-art deep learning model ResNet-50 has shown remarkable results in terms of colorectal polyp categorization [1], [8]–[10]. These results demonstrate CNNs' ability to improve diagnostic accuracy and aid in differentiating CRC lesions, opening the door to important developments in cancer detection and treatment approaches. CNNs are quite good at this, especially the more complex models like ResNet-50.

3.2 REPORT ON META ANALYSIS

This meta-analysis investigates the differentiation of benign and malignant colorectal polyps using machine learning methods. It covers studies conducted between 2015 and 2024 to comprehensively examine trends and advancements in this area.

Colorectal polyps are crucial precursors to colorectal cancer, making accurate differentiation essential for patient care. Machine learning offers promising solutions by analysing various data types, including colonoscopy images and histopathological samples.

The analysis reveals diverse machine learning algorithms employed for polyp classification, notably convolutional neural networks (CNNs) and deep learning techniques, which show significant success in accurately identifying benign and malignant polyps. These algorithms aid healthcare professionals in making informed diagnostic and treatment decisions.

Moreover, the meta-analysis highlights the evolution of machine learning methodologies, emphasizing innovative approaches and data augmentation techniques. These advances lead to substantial improvements in polyp classification accuracy, potentially transforming colorectal cancer screening and patient care practices.

In summary, this meta-analysis underscores significant progress in colorectal polyp analysis through machine learning. By synthesizing research findings, it provides insights into the efficacy and potential applications of machine learning in enhancing the differentiation of benign and malignant colorectal polyps, ultimately benefiting patient outcomes and healthcare delivery.

3.3 METHODS

Using Graph Pad Prism, a statistical analysis tool, data regarding the many techniques used to identify colorectal cancer in various research studies was gathered and arranged. Each method that was utilized on the dataset represented a distinct approach or model for the diagnosis of colorectal cancer. Before analysis started, the data were carefully examined to guarantee high quality and accuracy. Subsequently, descriptive statistical studies were conducted to show the variability and central tendency of performance indicators, such as the area under the receiver operating characteristic curve (AUC-ROC), across different datasets and years. These descriptive parameters demonstrated the variability and effectiveness of the several approaches examined for the diagnosis of colorectal cancer.

DATA EXTRACTED: FROM SYSTEMATIC REVIEWED PUBLICATIONS

Table 2. Data Extracted from Systematic Reviewed Publications.

YEAR	CNN	MIST	KERNEL BASED SVM	DEEP CONVOLUTIONAL MODEL	DEEP LEARNING MODEL
2020	5				
2022					1
2023		2			
2024			4	3	

DESCRIPTIVE STATISTICS TABLE.

Table 3. Descriptive Statistics Table.

	CNN	MIST	KERNEL BASED SVM	DEEP CONVOLUTIONAL MODEL	DEEP LEARNING MODEL
Number of values	1	1	1	1	1
Minimum	5.000	2.000	4.000	3.000	1.000
25% Percentile	5.000	2.000	4.000	3.000	1.000
Median	5.000	2.000	4.000	3.000	1.000
75% Percentile	5.000	2.000	4.000	3.000	1.000
Maximum	5.000	2.000	4.000	3.000	1.000
Range	0.000	0.000	0.000	0.000	0.000
Mean	5.000	2.000	4.000	3.000	1.000
Std. Deviation	0.000	0.000	0.000	0.000	0.000
Std. Error of Mean	0.000	0.000	0.000	0.000	0.000
Coefficient of variation	0.000%	0.000%	0.000%	0.000%	0.000%
Geometric mean	5.000	2.000	4.000	3.000	1.000
Geometric SD factor	1.000	1.000	1.000	1.000	1.000
Skewness					
Kurtosis					

Sum	5.000	2.000	4.000	3.000	1.000

VISUALIZED DATA

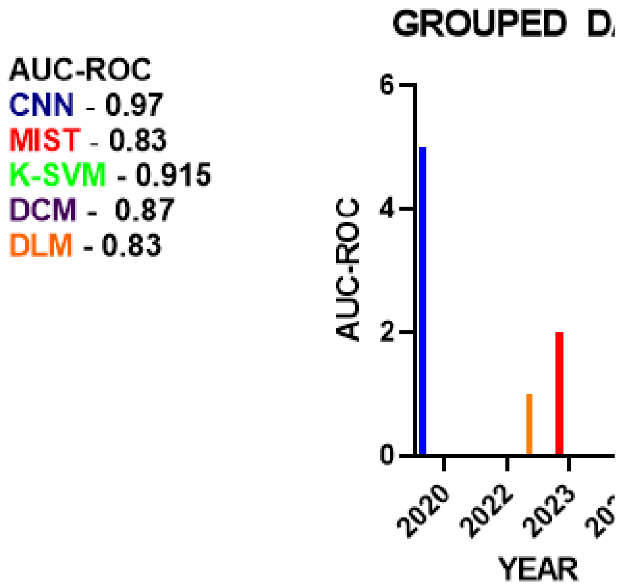

Fig 2. Graph Showing Grouped Data.

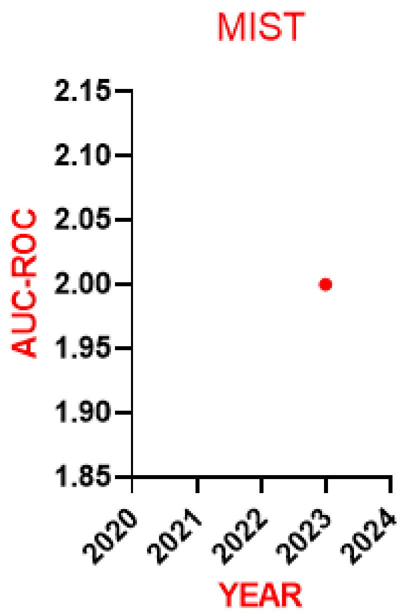

Fig 4. Analysis of MIST.

Case Study

Fig. 2 shows the machine learning models, their respective AUC-ROC score and their usage between the years 2020 and 2024. The graphs where created from the data in Tables 2 and 3.

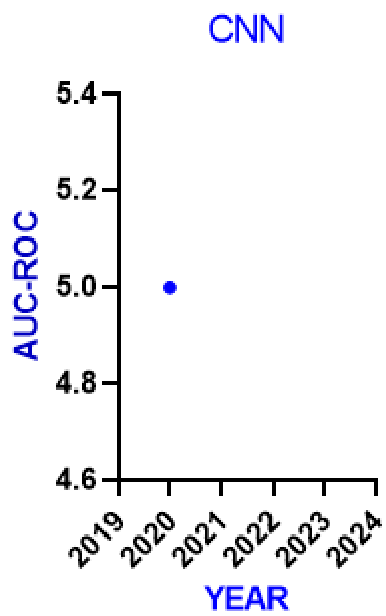

Fig 3. Analysis of CNN

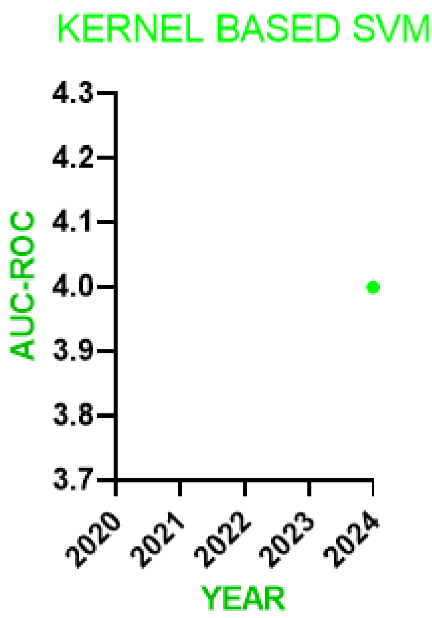

Fig 5. Analysis of Kernel Based SVM.

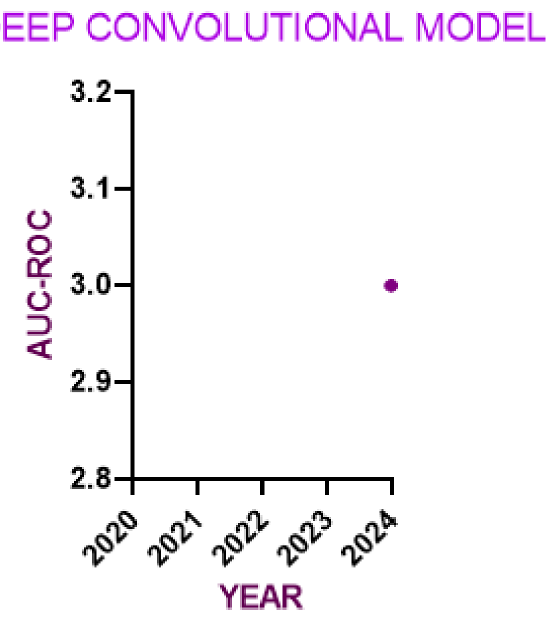

Fig 6. Analysis of Deep Convolutional Model.

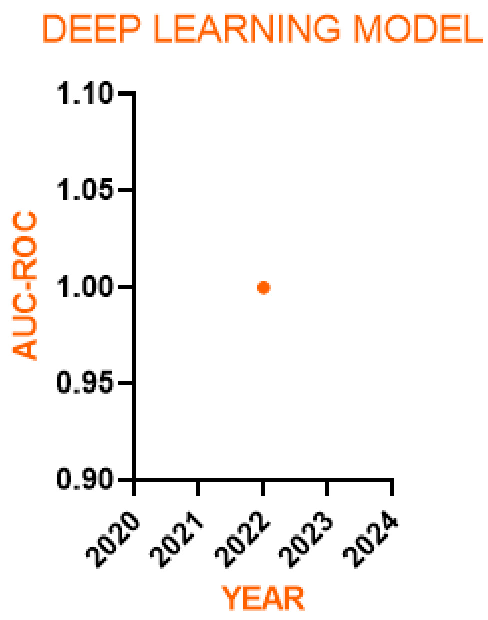

Fig 7. Analysis of Deep Learning Model.

DISCUSSION

- **DATA 1 Analysis (CNN)**

Fig. 3 shows that Convolutional Neural Networks are the best machine learning technique for distinguishing between different classes of colorectal polyps. The AUC-ROC score of 0.97 shows that it is highly effective in correctly ranking the predicted probabilities of polyp types, with minimal misclassification.

- **DATA 2 Analysis (MIST)**

Fig. 4 depicts high accuracy in the MIST learning technique which has an AUC-ROC score of 0.83.

- **DATA 3 Analysis (KERNEL BASED SVM)**

Fig. 5 shows Kernel Based SVM has the AUC-ROC score of 0.915 which proves that this machine learning model has high aptitude in distinguishing between different classes of colorectal polyps.

- **DATA 4 Analysis (DEEP CONVOLUTIONAL MODEL)**

Fig. 6 reveals Deep Convolutional Model which has an AUC-ROC value of 0.87, has good discriminatory ability in distinguishing between different classes of colon polyps. While not as high as some other reported values, it still suggests a solid performance of the model in classification tasks**.**

- **DATA 5 Analysis (DEEP LEARNING MODEL)**

Fig. 7 illustrates that having the AUC-ROC value of 0.83, indicate that the deep learning model is highly capable of distinguishing between different classes of colon polyps. However, there may be room for improvement to achieve higher discrimination.

RESULTS

Graph Pad Prism, a statistical analysis tool, was utilized to gather and arrange data on various methods used to detect colorectal cancer in different research studies. The data was categorized into different methods, with each one representing a specific technique or model used to diagnose colorectal cancer. Before the analysis was done, the data was carefully checked to make sure it was complete and of the highest level of quality. Statistical analyses were used to describe the average and distribution of performance metrics, such as AUC-ROC, over various datasets and years. These descriptive measurements provided data regarding the scope and efficacy of the several approaches studied for the detection of colorectal cancer.

4.0 DISCUSSION

A meta-analysis and systematic review supported a thorough examination of machine learning algorithms to distinguish between benign and malignant colorectal polyps, with the goal of measuring diagnostic accuracy and guiding clinical judgment. After reviewing a large number of research publications, convolutional neural networks (CNNs) were the most efficient, with an AUC-ROC score of 0.97. In contrast, ResNet-50 showed potential in the classification of polyps [1] and [8]-[10]. Other approaches, including MIST and Kernel-Based SVM, achieved AUC-ROC ratings of 0.83 and 0.915, respectively, demonstrating significant accuracy. When optical coherence tomography (OCT) was integrated into CADx systems, real-time diagnosis during colonoscopy improved and diagnostic precision increased [19] and [28]. Furthermore, CADx systems use machine learning algorithms to automate polyp classification, which improves the efficiency of biopsy procedures [18], [24], [25]. The complete meta-analysis strongly confirmed the findings of many research, confirming their precision and usefulness.

5. CONCLUSION

The systematic review and meta-analysis showed that machine learning algorithms can differentiate between benign and malignant colorectal polyps. CNNs had an AUC-ROC score of 0.97, surpassing ResNet-50, MIST, and Kernel-Based SVM. Furthermore, combining optical coherence tomography (OCT) with computer-aided diagnosis (CADx) technologies greatly improves colonoscopy real-time diagnosis. These findings emphasize the great progress being made in the application of cutting-edge technologies for colorectal cancer detection and classification, which will eventually improve patient treatment and reduce the number of colorectal cancer cases worldwide. Further research is needed to address present challenges and improve the implementation of machine learning algorithms in clinics and hospitals for the detection of colorectal polyps.

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