Artificial Intelligence–Integrated NIR-ICG Angiography for Intraoperative Assessment of Colorectal Anastomotic Perfusion: Preliminary Results of the ANTHEM 1.6 Platform

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***Abstract*—Background: Anastomotic leak remains one of the most severe complications following colorectal surgery, with reported rates ranging from 3% to 21% in low anterior resections. Intraoperative assessment of bowel perfusion using near-infrared fluorescence angiography with indocyanine green (NIR-ICG) has improved real-time visualization of microvascular flow; however, its interpretation remains largely subjective and operator-dependent. Artificial intelligence (AI), particularly convolutional neural networks (CNNs), may provide objective and reproducible perfusion analysis, potentially enhancing intraoperative decision-making.**

Materials and Methods:

We conducted a prospective, monocentric, cross-sectional observational study at AOU Luigi Vanvitelli (01/01/2023–31/12/2024), enrolling 54 patients (29 females, 25 males) undergoing laparoscopic left hemicolectomy with Knight–Griffen colorectal anastomosis for left-sided colorectal carcinoma. Intraoperative NIR-ICG angiography was performed to assess anastomotic perfusion. A CNN-based platform (Anthem 1.6) was developed and trained using dichotomously labeled images (adequate vs. inadequate perfusion) annotated by expert surgeons. The system integrates image-based features with clinical and patient-related variables. The architecture includes a Single Shot Detector module for region-of-interest identification and a VGG16-based classifier for perfusion stratification (good, poor, very poor). Model performance was evaluated using mean Average Precision (mAP) and threshold-based analysis.

Results:

Among 54 patients, the majority demonstrated good vascularization without postoperative leak (45/54). Poor or absent vascularization was associated with low-flow (n=1) and high-flow (n=1) leaks. In 2 cases (3.7%), the AI system predicted a potential leak despite intraoperative subjective assessment of adequate perfusion. The model achieved a mean Average Precision (mAP) of 0.87 at a threshold of 0.3 and 0.58 at a threshold of 0.5. Preliminary findings suggest that AI-assisted analysis may enhance detection of subtle hypoperfusion patterns not readily identifiable by visual inspection alone.

Conclusions:

The integration of AI with NIR-ICG fluorescence angiography represents a promising tool for objective intraoperative assessment of colorectal anastomotic perfusion. Although preliminary and limited by sample size, the Anthem 1.6 platform demonstrates potential in stratifying leak risk and supporting real-time surgical decision-making. Further data acquisition and external validation are required to confirm its predictive accuracy and clinical applicability in precision colorectal surgery.

***Keywords*— Artificial intelligence; Convolutional neural networks; Indocyanine green; NIR fluorescence; Colorectal**

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https://doi.org/10.17758/EIRAI21.F0426101

surgery; Anastomotic leak; Intraoperative decision support; Precision surgery.

I. INTRODUCTION

A. *Background*

Colorectal cancer is the third most common malignancy in men and the second in women, with increasing incidence and significant mortality [1]. Surgery remains the main curative treatment; however, colorectal procedures are associated with relevant complications, particularly anastomotic leakage, whose risk may increase due to extensive devascularization required for adequate lymphadenectomy [2,3]. Anastomotic leakage significantly affects postoperative outcomes, increasing hospitalization time, healthcare costs, and morbidity, with reported incidence ranging from 4.3% after colorectal resections to 3–21% in specialized procedures such as low anterior resection [4].

Indocyanine green (ICG) fluorescence angiography has emerged as a useful intraoperative tool for evaluating bowel perfusion and guiding surgical decision-making. ICG, a dye used for more than 50 years in medical diagnostics, binds to plasma proteins and allows real-time visualization of vascular perfusion using near-infrared laparoscopic imaging systems (Endoscopic Near Infrared Visualization, E.N.V.), enabling assessment of intestinal segments prior to anastomosis [5]. Although several studies have investigated the potential role of fluorescence angiography in reducing anastomotic leakage, image interpretation still relies mainly on the subjective evaluation of the surgeon [6,7]. A 2022 international consensus conference confirmed the safety and effectiveness of ICG across multiple surgical fields [8].

Artificial intelligence (AI), particularly convolutional neural networks (CNNs), has been increasingly applied in medical imaging, including colorectal cancer diagnosis using endoscopy, PET-CT, and histopathological images [9,10]. However, no studies have yet investigated the application of AI to evaluate bowel perfusion during colorectal surgery using near-infrared ICG fluorescence imaging. The aim of this study is therefore to develop CNN models trained on intraoperative fluorescence angiography images obtained during laparoscopic colorectal surgery to provide an objective assessment of intestinal perfusion, potentially reducing inter-observer variability and contributing to the prevention of anastomotic leakage. (Figure 1)

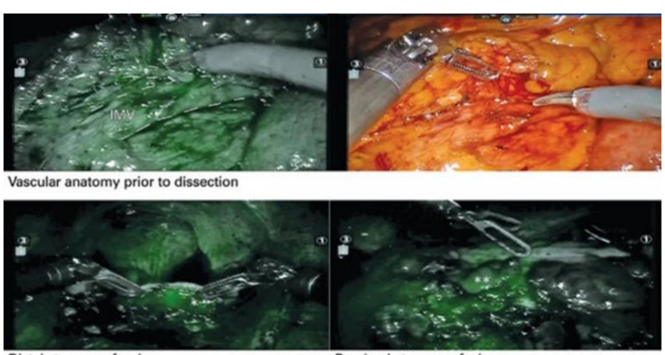

Fig.1. Vascular anatomy revealed by intraoperative near-infrared fluorescence imaging during robotic sigmoidectomy.

B. *Study Design*

The study is an observational, prospective, cross-sectional, single-center study, as it is conducted exclusively at the AOU Luigi Vanvitelli.

II. MATERIALS AND METHODS

A. *Recruitment*

The aim of this study is to enroll patients affected by colorectal cancer who are candidates for surgical treatment. All patients underwent the conventional diagnostic and therapeutic pathway according to international guidelines and according to the decision of the institutional Multidisciplinary Oncology Group (GOM); therefore, no modifications to routine clinical practice are planned. Patients affected by neoplasms eligible for surgical treatment were operated on at the Medical and Surgical Department of High Specialty and at the Department of Surgery, Orthopedics and Hepatogastroenterology, Universitary Policlinico "L. Vanvitelli", Naples, Italy.

Inclusion criteria:

• Men or women;

• Diagnosis of colon or rectal cancer requiring surgical treatment;

Exclusion criteria

• Subjects who refuse or are unable to provide participation through informed consent;

• Unresectable tumors;

• Procedures performed entirely or partiall (i.e., converted from minimally invasive surgery) as open surgery (laparotomy);

• Written informed consent.

B. *Assessment of Tissue Perfusion with NIR-ICG*

The study protocol includes the evaluation of perfusion of the colonic stumps and the anastomosis in oncologic colorectal surgery using indocyanine green. This practice allows verification of tissue perfusion through fluorescence imaging. The protocol does not involve any modification to standard clinical-surgical practice. The use of ICG is already widely documented in the literature.

All patients undergo bowel preparation with osmotic laxatives two days before surgery and an evacuative enema on the morning of surgery. The day before surgery, the patient begins antibiotic prophylaxis with Metronidazole 500 mg IV three times daily. Minimally invasive surgery is performed laparoscopically according to international guidelines, without any modification related to this study.

During surgery, colorectal perfusion assessment is performed as follows: intraoperative angiographic evaluation with NIR-ICG during colorectal surgery for neoplasms of the descending colon, sigmoid colon, and rectum is carried out after mesenteric preparation with ligation at the origin of the inferior mesenteric vessels and after completion of the anastomosis. ICG is injected into the bloodstream through a peripheral venous access (0.011 ml/kg followed by a 10 cc saline flush).

After 30–60 seconds, the colonic tissue under study is visualized using an infrared light source with wavelengths between 700 and 900 nm, positioned at a constant distance of 5 cm from the tissue (in our case, a laparoscopic system with Rubina 4K camera Karl Storz®, NIR mode superimposed with green light). The video procedure is recorded using the AIDA video acquisition system integrated into the Rubina 4K Karl Storz laparoscopic platform, without any patient-identifying data; each case is assigned only a numerical code that cannot be associated with the individual subject.

The surgical procedure is then completed according to standard practice. Postoperative management includes antibiotic prophylaxis for three days (Metronidazole 500 mg IV three times daily + Cefazolin 1 g IV twice daily), nutritional support through Total Parenteral Nutrition (TPN) for two days, with resumption of oral feeding with a liquid diet on postoperative day 3 and a solid diet on postoperative day 4. Subjects will be enrolled only after signing informed consent. The study will be conducted in accordance with the ethical guidelines of the Declaration of Helsinki

C. Methodology

1. Artificial intelligence training

The Anthem 1.6 platform is positioned within the framework of Computer-Aided Diagnosis (CAD) systems, namely computerized tools that support medical diagnosis. The analyzed datasets were obtained from images/videos and additional clinical data. The strength of the project lies in the availability of as much information as possible regarding the biological, clinical, and diagnostic characteristics of tumor pathology. Therefore, the goal is to move beyond an exclusively diagnostic evaluation of patient data and instead integrate these data with a broader set of information that enables the training of artificial intelligence systems.

Imaging examinations are thus incorporated into an automated analysis system, namely a form of artificial intelligence. The system analyzes the acquired images together with a set of contextual information that typically derives from the physician’s clinical expertise. For example, a simple ultrasound image of a radiologically detected nodule may not be diagnostic or may be difficult to interpret. Artificial intelligence could integrate the same image with additional parameters, such as the vascularization of the lesion. To achieve this, the device uses algorithms based on Machine Learning systems, allowing it to suggest that a specific chromatic density observed in imaging may be associated with a particular diagnosis.

The primary endpoints are to identify which genetic, biomolecular, and clinical-anamnestic factors are most relevant for defining patients at high risk of anastomotic dehiscence. The secondary endpoint is to design a CAD system capable of effectively identifying one or more predictive factors of anastomotic devascularization, thereby supporting the surgeon during the intraoperative (i.o.) phase.

The entire framework is therefore based on a clinical data management platform that uses predictive models based on Deep Learning and Machine Learning. The objective is to make this tool widely available across healthcare facilities, enabling the system to automatically recognize areas of devascularization and, when integrated with additional patient data—from anamnestic to genetic information—to analyze surgical videos with a form of “expert vision,” capable of identifying patients at high risk.

With regard to colorectal cancer surgery, particularly colo-rectal anastomosis, the Anthem 1.6 platform includes two modules: one for detection of the anastomotic line and another for its classification into good or poor vascularization. The first module consists of a Single Shot Detector neural network, designed to analyze the video frame-by-frame in order to identify the surgical anastomosis. During the first 20 procedures, the system is trained using a Region of Interest (ROI) selected by the surgeon.

This system has two subcomponents: a backbone model, whose purpose is to learn the features of the tissues of interest, and a detection model, which uses the features extracted by the backbone model to generate bounding boxes. The VGG16 network, a convolutional neural network (CNN) associated with the ImageNet dataset, is used for this purpose. Tissues presenting different degrees of vascularization are then identified through the second module. (Figure 2)

More specifically, AlexNet is used to distinguish the anastomosis among different vascularization classes. The network involved was pre-trained on ImageNet, and the task was solved through fine-tuning. The mean Average Precision (mAP) metric was used for performance evaluation. These methods generated a set of paired data for different cross-validation procedures.

More precisely, the system performs predictive evaluations by generating bounding boxes for each image, which overlap with the ground-truth box (measured through Intersection over Union, IoU). Since IoU ranges between 0 and 1, a prediction is considered correct if the IoU value exceeds the predefined threshold. Precision and recall are determined based on the number of correct diagnoses, and their validity is calculated by measuring the percentage of correct predictions and the reliability of the predictions themselves. The mAP corresponds to the mean of the average precision values, namely the area under the precision–recall curve.

The dataset was collected from the Oncologic Surgery Unit of Prof. Docimo, Department of Advanced Medical and Surgical Specialties, at the University Hospital of Campania “Luigi Vanvitelli” in Naples, Italy, where the vascularization of the anastomosis was defined and classified.

The study sample, collected from 01/01/2023 to 31/12/2024, consists of 54 patients (29 F and 25 M). All patients underwent pan-colonoscopy and endoscopic biopsy, with histopathological confirmation of left-sided colon carcinoma, followed by surgical treatment consisting of laparoscopic left hemicolectomy and colo-rectal anastomosis using the Knight and Griffen technique, with intraoperative evaluation of anastomotic vascularization using ICG-NIR.

From more than 100 colorectal surgical procedures, a drop-out rate of 47% was observed, including:

- Conversion to open surgery: 12%
- Colo-anal anastomosis: 5%
- Learning-curve errors in procedure standardization: 15%
- Incomplete diagnostic or operative data: 10%

- Postoperative follow-up < 6 months: 5%

The follow-up period ranged from 3 to 24 months. For each patient, a surgical endoscopic video, corresponding images, and a mask identifying the Region of Interest (ROI) are available.

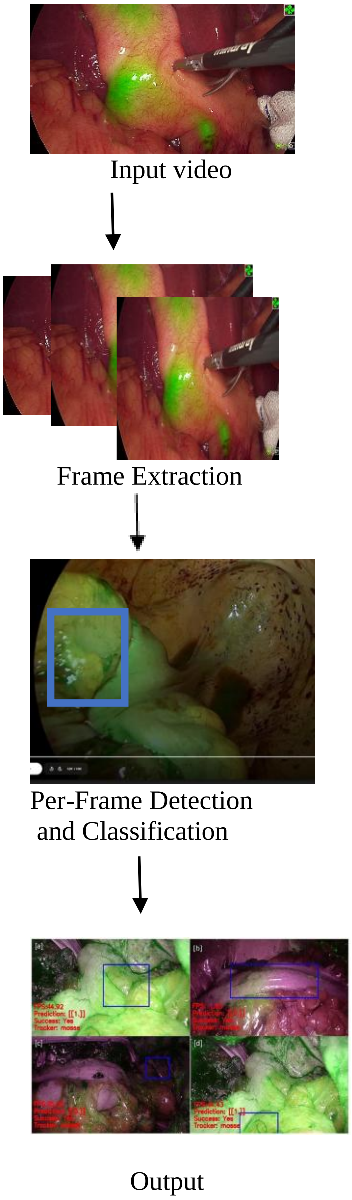

Fig. 2. Convolutional Neural Network (CNNS) system wich belong to the Deep Learning (DL) family.

2. Elaboration system

Figure 3 shows the results obtained by applying another algorithm proposed by the Corcione–Peltrini group to frames from the dataset with good and poor perfusion. For each analyzed frame, the corresponding Region of Interest (ROI) is indicated.

Specifically, Fig. 4a and 4d have ROIs classified as well perfused (high amount of green signal) with a prediction output of 1. Conversely, Fig. 4b and 4c have a prediction output of 0, as the ROIs are considered by the algorithm to be poorly perfused, either due to a low degree of green signal or to a non-uniform distribution of green within the selected ROI.

In all the considered cases, the correctness of the classification was confirmed by the surgeons.

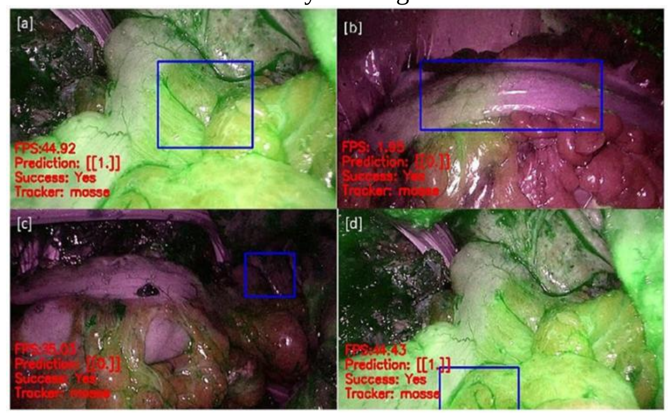

Figure 3. Four frames from the dataset with the corresponding ROIs: (a) and (d) show ROIs with adequate perfusion (high amount of green signal) and prediction = 1. (b) and (c) show prediction = 0, as the ROIs are inadequately perfused (low amount of green signal and/or non-uniform ICG diffusion) [11,12].

Regarding colorectal cancer, the scientific objective of the Anthem 1.6 program was to assess whether the system could identify good or poor vascularization of the colon anastomosis and predict the actual potential risk of anastomotic leak, integrating the surgeon’s diagnostic interpretation obtained using ICG-NIR laparoscopic instrumentation.

Furthermore, by combining surgical endoscopic videos, images, and a set of variables (related to lesion and patient characteristics), a secondary objective, still under development, is to enable a more precise stratification of population risk classes for colorectal anastomotic leak and to achieve a better definition of surgical protocols.

III. RESULTS

For this work, we used a platform similar to the Synergy-Net Platform [13]. This is similar to the one demonstrated by the Corcione-Peltrini group, which has already yielded good results. Our goal is to develop a new ANTHEM 1.6 platform that integrates the two previous ones. The aim is to formulate a preoperative assessment of the anastomosis's stability through the use of patient data and tabular information, such as genetic, medical history, and clinical data. (Figure 4)

https://doi.org/10.17758/EIRAI21.F0426101

Fig. 4. Classification of the anastomotic line and vascularization. The type of tumor tissue is confirmed through the performed histopathological report.

The performance reproduced on a theoretical model and using videos acquired during open surgery appears promising: the Anthem 1.6 digital platform, particularly the dedicated Workstation, when compared with the “retrospective” evaluation by expert surgeons, demonstrated notable performance (TABLE 1 and TABLE 2).

TABLE 1. CONFUSION MATRIX FOR THE CLASSIFICATION TASK.

	No Leak	**Low flow leak**	**High Flow Leak**
Good Vascularization	45	0	0
Poor Vascularization	7	1	0
No or Very poor Vascularization	0	0	1

This allows visualization of the system’s performance, where rows represent the predicted class and columns represent the true class. Notably, there are data from 2 patients (3.7%) in which the surgeon considered the vascularization adequate, but the system was able to predict a potential anastomotic leak.

TABLE II. RESULTS OF THE VASCULARIZED TISSUE DETECTION MODULE.

Thresholds	MAP
0.3	0.87
0.5	0.58

Two different Intersection-over-Union (IoU) thresholds are considered. Accuracy is defined as the ratio between predicted observations and total observations.

The output is:

- A devascularized anastomosis indicates a suspicious sign or potential risk of anastomotic leak.
- The diagnosis is performed by the system.

The objective of the Anthem 1.6 program is to ensure that the evaluation of the colo-rectal anastomosis achieves a predictive accuracy comparable to or better than that of expert surgeons.

Furthermore, future developments aim to provide real-time diagnoses and a predictive estimation of anastomotic leak risk.

IV. Discussion and Conclusion

Anastomotic leaks are often multifactorial events, arising both from surgical factors and patient-specific characteristics, and are more likely to occur during procedures that do not meet the highest quality standards. Therefore, it would be important, if possible, to determine the actual frequency of association between anastomoses with good, poor, or very poor vascularization in order to identify factors that may increase the risk of anastomotic leak. This information could, for example, guide the decision to reconstruct a new anastomosis.

Once the leak-related risk has been assessed, it is possible to evaluate the potential impact of the aforementioned variables on high- or low-flow patient-related risk, providing valuable information on the system’s predictive potential. This approach would create the conditions to tailor surgical anastomosis and postoperative follow-up in a way that is more detailed and individualized than current methods allow.

Regarding the role of anastomotic vascularization in predicting leak events, the work so far has focused on collecting a significant number of patient data and using these data to “train” the system. Prior to initiating the intelligent analysis (CNN-supported diagnosis), the system was prepared and trained to recognize specific surgical videos and images. While this process may be intuitive for an experienced clinician, it is not for a machine that is still “inexperienced.”

In the future, this system could: identify vascularization defects that might not be detectable with other investigations, improve the diagnostic accuracy of ICG-NIR, Select which patients are suitable for a specific anastomosis, and provide support to less-experienced surgeons. All of this could enable increasingly precise and early diagnosis. A conditio sine qua non is the need to continuously train the machine with ever-growing datasets, particularly with continuous data from the entire diagnostic-therapeutic process. Ultimately, the goal is to develop a preoperative protocol or surgical treatment tailored to the specific neoplastic lesion of an individual patient, moving toward precision medicine.

The Anthem 1.6 Information System (IS) aims to create an AI-based Computer-Aided Diagnosis (CAD) system designed to support the physician across a range of pathological conditions, leveraging the full advantages that an integrated analysis can provide. In this context, calibrating current surgical choices for the construction and management of the colo-rectal anastomosis and identifying personalized pre- and postoperative protocols for patients at high risk of dehiscence has become an increasingly important necessity to achieve higher standards in postoperative morbidity.

During surgery, there are three main sources of error when diagnosing a poorly vascularized anastomosis**:**

- The surgeon is not sufficiently experienced.

- The surgeon has not adequately analyzed patient-dependent variables.
- The surgeon has not used ICG-NIR technology.

To address this, it is necessary to enhance the panoramic view of intraoperative devices and optimize multiple variables, ensuring complete and optimal visualization and supporting the surgeon in intraoperative decision-making.

Accordingly, the design of Anthem 1.6 has dedicated the main software programming to the detection module: the "detection" of objects, supported by anatomical landmarks and vascularization details within the Region of Interest (ROI), enabling discrimination between well-perfused and poorly perfused anastomoses ("Classification").

The Anthem 1.6 program is intended to enable early detection of anastomotic vascularization during ICG-NIR examination of colo-rectal anastomoses in left colon cancer surgery. Furthermore, this technology can provide a real-time diagnostic implementation, capable of supporting the operating surgeon during the examination itself. The ultimate goal is to provide the surgeon with the probability that the anastomosis is effectively well-performed.

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