Caring is Sharing – Exploiting the Value in Data for Health and Innovation
M. Hägglund et al. (Eds.)

doi:10.3233/SHTI230208

Convolutional Neural Networks for Optical Discrimination Between Histological Types of Colorectal Polyps Based on White Light Endoscopic Images

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Abstract. The objective of this study was to compare different convolutional neural networks (CNNs), as employed in a Python-produced deep learning process, used on white light images of colorectal polyps acquired during the process of a colonoscopy, in order to estimate the accuracy of the optical recognition of particular histologic types of polyps. The TensorFlow framework was used for Inception V3, ResNet50, DenseNet121, and NasNetLarge, which were trained with 924 images, drawn from 86 patients.

Keywords. Deep learning, convolutional neural networks, polyps, endoscopy

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1. Introduction and Background

Artificial Intelligence (AI) has already been tested in every aspect of the medical field, namely detection and diagnosis, therapy, and prognosis of diseases. Since the global summit of AI in Gastroenterology held in the USA in 2019, it has been well acknowledged that AI and especially what is called deep learning, will play an important role in the treatment of colorectal polyps [1]. Especially interesting is its application to the histological characterization of these polyps by means of an optical biopsy. This kind of histological determination through the imaging characteristics of a particular polyp has been a conundrum for decades since it has been recognized as a useful asset during colonoscopy either as a screening tool or as a diagnostic modality, for a variety of indications.

Optical biopsy, circumventing the histopathological analysis, is considered important during colonoscopy because it permits the immediate and direct decision of the endoscopist on the risk level of the lesion and consequently on the need for excision or selection of the best endoscopic method for removal, following a cost-effective approach. This approach aims to decrease complications and at the same time to save money, time, and effort for any healthcare system that is based on restricted human and economic resources [2].

Until now the goal of a reliable optical biopsy was concentrated on the technological achievements of better image quality and analysis that will offer better discrimination of the anatomical structures of the polyps during real-time endoscopy, either by means of magnification endoscopes or virtual chromoendoscopy methods [e.g NBI (narrow band imaging)]. These approaches demand specialized and expensive equipment and time-consuming training of experts, which will always depend on the experience and skills of the operator, rendering the whole process mainly subjective, although several classifications have been perpetually adapted in order to reduce bias [3,4]. As a consequence of the trade-off between expectations and necessity, it was considered that artificial intelligence could provide a second opinion to the endoscopist during routine clinical practice for the optical determination of colorectal polyps, probably without the need for the additive cost of endoscopic accessories, while at the same time being feasible even for novice endoscopists who lack the experience of a trained eye [5,6]

The scope of this study was to compare different convolutional neural networks (CNN), as employed in deep learning (DL) algorithms, used on white light images of colorectal polyps acquired during the process of a colonoscopy, in order to estimate the accuracy of the optical recognition of particular histologic types of polyps. Large bowel carcinogenesis has been proven to be a sequential process starting from low-risk lesions progressively transformed to higher risk and finally to cancer. The purpose of a colonoscopy is to prevent this escalation by detecting and removing precancerous polyps to reduce the incidence and mortality of colon cancer. This approach has been proven effective when applied to screening programs that have been addressed to millions of eligible persons [7]. On the other hand, the workload and interventional endoscopies that are produced are so immense that a tool, which will have the ability to accurately classify these polyps, can be expected to reduce the burden on clinical, laboratory, and human resources. This study has also included in the analysis, besides the common precancerous lesions called adenomas, the also important but less investigated and more difficult to characterize sessile serrated adenomas (SSA/P), which constitute the alternative carcinogenesis pathway [8].

2. Methods and Materials

This study was conducted in a public tertiary care hospital in Greece and has been approved by the corresponding Institutional Review Board. The patients who were admitted to the endoscopy unit of a tertiary hospital for the execution of a colonoscopy for several indications were prospectively included in the study except for chronic idiopathic bowel disease and syndromes of polyposis. The individuals were submitted to colonoscopy following routine clinical practice and during the procedure, any polyp that was discovered was photographed using high-definition imaging under white light endoscopy (WLE) with as much clarity as possible avoiding bubbles, feces, blur vision, etc., and stored with a resolution of 720X576 pixels. Then, the polyps were fully resected, and every specimen was put in a different vial for the purpose of cross-referencing between the histopathological report and the specific lesions. This report was used as the gold standard for the characterization of any polyp. The study includes the training process of the CNNs which were provided with polyp images under two main categorization schemes. The first one was a 2-class division between neoplastic (adenomas with low and high-grade dysplasia) and non-neoplastic (hyperplastic) polyps and the second was a 3-class division between adenomas vs hyperplastic vs sessile serrated adenomas (SSA/P).

The Tensorflow framework was used for Inception V3, ResNet50, DenseNet121, and NasNetLarge, which were trained with 924 collected images, drawn from 86 patients, after their pre-processing based on the ImageNet database through a transfer learning process. During training, the same hyper-parameters were set and used for all the networks, including learning rate, batch, epochs, etc. The performance of the CNNs on the histological classification process was evaluated based on Accuracy, Loss as well as the areas under the curves (AUC/ROC curves). We present the results of the best two CNNs that provide the highest accuracy with the lesser loss and the best probability of the right selection during their prediction according to ROC curves.

3. Results

There were 86 patients with a median age of 64 years (range 24-92) and 55% of them were male. 53% of the patients were submitted to colonoscopy to search for polyps either as screening, surveillance, or an indication for polyp excision. The patients carried 191 polyps in total with a median size of 8mm (1st-3rd interquartile: 6-10mm). These polyps were 55% adenomas, 22% hyperplastic, and 17% sessile serrated lesions. There were 924 images captured and stored for analysis without any further enhancement.

The CNNs with the most accurate prognosis were the DenseNet121 and Inception v3 in both the categorization schemes (Table 1). The higher accuracy in both categories was achieved by DenseNet 121 and estimated at 84.7% (Figure 1) and 73.6% respectively.

Table 1. Evaluation metrics of the two best-performing CNNs for the optical classification of colorectal polyps in two categories. 1st category: neoplastic vs non-neoplastic, 2nd category: adenomas vs hyperplastic vs SSA/P

Metric/Method	1st category		2nd category	
	DenseNet121	Inception v3	DenseNet121	Inception v3
Accuracy	84.7%	77.8%	73.6%	70.8%
Loss	0.631	0.848	0.999	1.193
AUC ROC	0.886	0.826	0.815	0.852

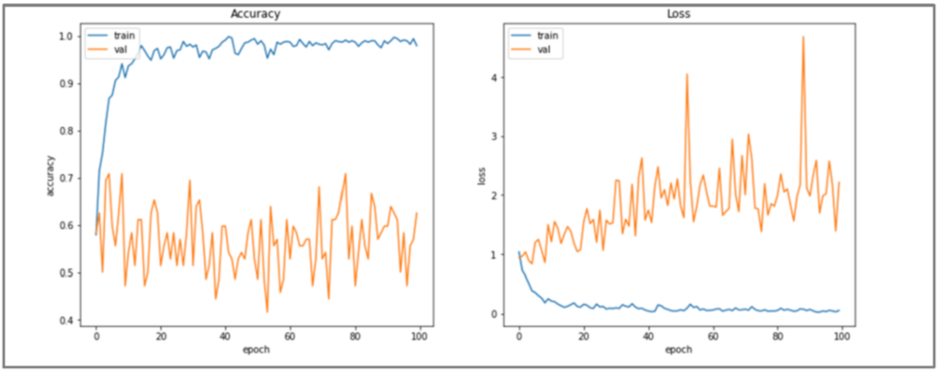

Figure 1. The epoch versus accuracy and loss plots of the DenseNet 121 model on 1st category on train and validation datasets.

4. Discussion

The ability of CNNs to provide a classification for an optical biopsy using white-light endoscopy images of colorectal polyps has been presented in several retrospective studies rendering an accuracy between 67.3-94.4% [3, 9-11]. This wide range of efficacy is probably attributed to the type of CNNs trained and the modulation of their hyper-parameters by each of the different research groups. Furthermore, the actual number of images and the methods to augment their variety and quantity by means of image enhancement as well as the preselection of CNNs with transfer learning might have made a considerable impact on the outcome. Additionally, the type and classes of histologic categorization of polyps, which are utilized by each research group to train the model are crucial, and probably affect the level of difficulty in discriminating certain histological types with respect to others, based on their image characteristics.

In our study, the images have been prospectively collected restricting any selection bias and apart from the classical categorization between neoplastic and non-neoplastic polyps, a venture has been undertaken to include in one of its classifications the SSA/P adenoma for which there have not been enough data in WLE so far. The latter lesions are notorious for their high detection missing rate during colonoscopy, which is attributed to their morphology, location, structure, and size. Furthermore, these lesions have presented dilemmas in their histopathological recognition as the interobserver variability and constantly changing nomenclature have recently indicated. This study has proven a satisfactory accuracy of 84.7% for the DenseNet121 upon WLE during routine clinical practice conditions to select neoplastic lesions and still maintaining a very promising accuracy of 73.6% for discriminating between adenomas, SSA/P, and non-neoplastic lesions. This model seems quite robust demonstrating a quite acceptable level of error gradient and a quite confident AUC of 0.886. This level of accuracy is also comparable to that of expert endoscopists who use image-enhanced endoscopy (IEE) like NBI (accuracy 85.6%) or BLI (accuracy 75%), as prospective and multicenter studies have shown [12,13]. We stress that our results have been achieved without any image enhancement or advanced endoscopic systems.

Admittedly, our study has some limitations. The results are preliminary in the sense that this is an ongoing trial, which is still at the beginning of training the model. The number of images is still growing, and we expect to enrich our database for further validating the models. Although the training of the model is based on WLE images which can be considered inferior in quality and analysis of specific features, it was the first priority to reflect the capabilities of CNNs under real-world endoscopic conditions that exist in most endoscopy units.

5. Conclusion

The utilization of convolutional neural networks could become useful in the future as an adjunct tool during real-time decision-making of optical histological determination of colorectal polyps by the endoscopists since they could provide acceptable accuracy that at least reach human experts and, at the same time, present promising outcomes even for the most difficult endoscopic lesions. If these results are confirmed by the progress of this study or other research, then artificial intelligence would be able to be applied in everyday clinical practice, thus reducing the impact of disease and the human effort to address it.

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