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Enhancing Pulmonary Embolism Detection in COVID-19 Patients Through Advanced Deep Learning Techniques

Georgios FERETZAKIS[a,b,1,†], Konstantinos DALAMARINIS[c,†], Dimitris KALLES[a], Chairi KIOURT[d], Georgios PANTOS[c], Ioannis PAPADOPOULOS[c], Spyros KOURIS[c], Vassilios S. VERYKIOS[a], George IOANNAKIS[d], Evangelos LOUPELIS[e] and Aikaterini SAKAGIANNI[f]

[a] *School of Science and Technology, Hellenic Open University, Patras, Greece*
[b] *Department of Quality Control, Research and Continuing Education, Sismanogleio General Hospital, 15126 Marousi, Greece*
[c] *Department of Radiology, Sismanogleio General Hospital, 15126 Marousi, Greece*
[d] *Athena-Research and Innovation Center in Information, Communication and Knowledge Technologies, Xanthi, Greece*
[e] *IT department, Sismanogleio General Hospital, 15126 Marousi, Greece*
[f] *Intensive Care Unit, Sismanogleio General Hospital, 15126 Marousi, Greece*
† Equal contribution (first authors)

Abstract. The intersection of COVID-19 and pulmonary embolism (PE) has posed unprecedented challenges in medical diagnostics. The critical nature of PE and its increased incidence during the pandemic underline the need for improved detection methods. This study evaluates the effectiveness of advanced deep learning techniques in enhancing PE detection in post-COVID-19 patients through Computed Tomography Pulmonary Angiography (CTPA) scans. Using a dataset of 746 anonymized CTPA images from 25 patients, we fine-tuned the state-of-the-art Ultralytics YOLOv8 object detection model, which was trained on 676 images with 1,517 annotated bounding boxes and validated on 70 images with 108 bounding boxes. After 200 epochs of training, which lasted approximately 1.021 hours, the YOLOv8 model demonstrated significant diagnostic proficiency, achieving a mean Average Precision (mAP) of 0.683 at an IoU threshold of 0.50 and a mAP of 0.246 at the IoU range of 0.50:0.95 in the validation dataset. Notably, the model reached a maximum precision of 0.85949 and a maximum recall of 0.81481, though these metrics were observed in separate epochs. These findings emphasize the model's potential for high diagnostic accuracy and offer a promising direction for deploying AI tools in clinical settings, significantly contributing to healthcare innovation and patient care post-pandemic.

Keywords. Pulmonary Embolism, COVID-19, artificial intelligence (AI), deep learning, computed tomography (CT)

[1] Corresponding Author: Georgios FERETZAKIS, PhD, School of Science and Technology, Hellenic Open University, Patras, Greece; E-mail: georgios.feretzakis@ac.eap.gr.

1. Introduction and Background

Pulmonary embolism (PE), a life-threatening condition marked by clots blocking the pulmonary arteries, has been a focal point of medical concern, notably during the recent COVID-19 pandemic. Although the acute phase of the COVID-19 crisis has declined, its correlation with thromboembolic events such as PE provides crucial insights for future healthcare strategies. Studies during the pandemic revealed a heightened incidence of PE among COVID-19 patients, emphasizing the importance of robust diagnostic measures. Reports indicated PE prevalence rates as high as 30% in COVID-19 patients admitted to intensive care units, underscoring the critical need for accurate diagnostic tools [1,2].

Computed Tomography Pulmonary Angiography (CTPA) remains the gold standard for diagnosing PE. However, the method is not without challenges, including the extensive number of images for radiologists to review and the risk of false positives, which may complicate the treatment pathway [3]. The advent of deep learning technology in medical imaging presents a promising solution to these challenges, potentially transforming the diagnostic landscape for conditions like COVID-19 [4,5].

The integration of deep learning into the diagnostic process for PE in post-COVID-19 patients remains a relatively untapped research avenue. This gap is partly due to the novel challenges posed by the pandemic, such as distinguishing between PE and lung abnormalities caused by COVID-19 [6,7]. Recent studies highlight the potential of AI to enhance PE detection. Innovations in AI-driven diagnostics have shown promise in reducing the time required to identify PE, crucial for timely treatment, particularly in post-pandemic healthcare settings [7]. Further research has demonstrated the efficacy of deep learning models in detecting PE with greater sensitivity, suggesting these tools could serve as valuable adjuncts to traditional diagnostic methods [8]. Moreover, novel AI models capable of distinguishing between PE and post-COVID-19 lung infiltrates have begun to emerge, indicating the potential for highly specialized diagnostic tools in the post-pandemic era [9]. This study aims to leverage the latest in AI technology to improve both the classification and localization of PE in CTPA scans, offering enhanced diagnostic capabilities that are vital for navigating the complex clinical landscape shaped by the pandemic.

2. Materials and Methods

The dataset underpinning this research was meticulously assembled at a public tertiary care hospital in Greece, specifically within the Radiology Department of Sismanogleio General Hospital. The Institutional Review Board of Sismanogleio General Hospital granted approval for the study and all procedures followed were in accordance with the ethical standards of the responsible committee and with the Helsinki Declaration of 1975, as revised in 2000. The dataset consists of Computed Tomography Pulmonary Angiography (CTPA) images from COVID-19 patients, all of which were anonymized prior to analysis to uphold the confidentiality of patient information. These images were systematically reviewed for the presence of pulmonary embolism (PE) by two seasoned radiologists, boasting 17 and 26 years of experience in thoracic imaging, respectively. This rigorous review process leveraged the hospital's Picture Archiving and Communication System (PACS), highlighting the integration of clinical expertise and advanced technology in identifying PE manifestations.

The dataset utilized in this study presents a detailed account of computed tomography pulmonary angiography (CTPA) scans segmented into two groups: the training set, which contains 676 images annotated with 1,517 bounding boxes from 20 distinct patients, and the validation set, which comprises 70 images with 108 bounding boxes from 5 unique patients. The training set demonstrates an average of 2.24 bounding boxes per image, indicative of the multifaceted nature of pulmonary embolism (PE) manifestations, while the validation set exhibits an average of 1.54 bounding boxes per image, providing a rigorous benchmark for model validation. The overall dataset average of 2.18 bounding boxes per image underscores the breadth and diversity of the PE instances encompassed in the 746 images utilized for the study. Additionally, the mean figure of 31.08 images per patient delineates the substantial variance in PE presentations, further highlighting the comprehensive scope of the dataset in capturing a wide array of clinical scenarios. In the pursuit of enhancing pulmonary embolism (PE) detection through deep learning methodologies, we employed the advanced Ultralytics YOLOv8 framework for object detection tasks [10]. This choice was driven by the model's optimal balance between accuracy and computational efficiency, making it ideally suited for our dataset's complexities and the goal of detecting intricate pulmonary embolism features within CTPA images. The model training was performed on a Tesla V100-SXM2-16GB GPU. The training regimen spanned 200 epochs, with configurations meticulously tailored to the dataset's characteristics and the specific demands of PE detection. Parameters such as learning rate, batch size, and image size were carefully chosen to optimize model performance. Notably, we employed a batch size of 16 and an image resolution of 640x640, considerations made to balance between model accuracy and computational efficiency. Throughout the training process, we observed significant improvements in model performance metrics, including precision, recall, and mean Average Precision (mAP). These metrics were rigorously monitored to ensure that the model's detection capabilities were aligned with our objectives of high accuracy and reliability in PE detection.

3. Results

In our research, we meticulously evaluated the performance of the Ultralytics YOLOv8, a state-of-the-art object detection model, which we fine-tuned to detect pulmonary embolism (PE) within computed tomography pulmonary angiography (CTPA) scans. We compiled a dataset of 746 CTPA images from 25 anonymized patients, organizing it into a training set of 676 images with 1,517 annotated bounding boxes and a validation set of 70 images with 108 bounding boxes. This structured division ensured a comprehensive training regimen and a rigorous validation process.

After completing 200 epochs of training, taking approximately 1.021 hours, the YOLOv8 model demonstrated significant diagnostic proficiency. It achieved a mean Average Precision (mAP) of 0.683 at an Intersection over Union (IoU) threshold of 0.50 and a mAP of 0.246 at the IoU range of 0.50:0.95 in the validation dataset, confirming its strong performance across diverse patient cases. In assessing the performance of our deep learning model, we observed a maximum precision of 0.85949 and a maximum recall of 0.81481 in the validation dataset. It is important to note that these metrics were achieved in separate epochs, reflecting the model's peak capabilities throughout the training process. These results demonstrate the model's potential for high diagnostic accuracy in the detection of pulmonary embolism in CT images.

One notable instance from the validation set highlights the model's capabilities: an image depicting a section of a CTPA scan with a high confidence detection of PE, marked as "PE 0.9." This indicates that the model has identified a suspected area of pulmonary embolism with a 90% confidence score, illustrating the practical application of the model in a clinical diagnostic setting (Figure 1).

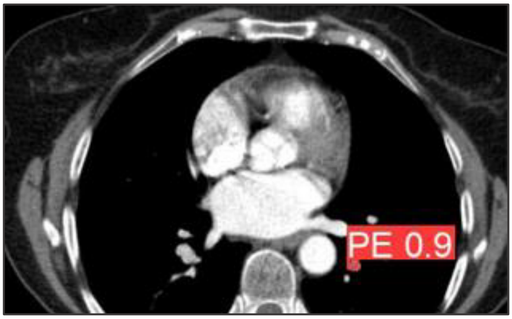

Figure 1. An example of a CTPA scan from the validation set demonstrates the YOLOv8 model's detection capabilities, where it identifies a suspected pulmonary embolism with a 90% confidence level.

4. Discussion

The findings from this study hold significant implications for the integration of artificial intelligence in medical imaging, particularly in the post-COVID-19 era where healthcare systems remain alert to the long-term impacts of the pandemic. The efficacy of the YOLOv8 model in identifying PE instances in CTPA scans reinforces the transformative potential of AI technologies in diagnostic radiology. Our results revealed a high mean average precision, indicative of the model's capability to detect true positive PE instances with remarkable accuracy. This accuracy is paramount in emergency medicine, where the timely and correct diagnosis of PE can drastically influence patient management and outcomes.

The study's success is rooted in the meticulous data preparation and the deployment of advanced deep learning algorithms, demonstrating that the strategic application of AI can yield reliable diagnostic support tools. The collaborative effort between AI specialists and seasoned radiologists was a crucial element, ensuring the model's training and validation were grounded in clinical relevance and expertise. The performance rates underscore the model's ability to detect actual instances of PE while minimizing the occurrence of false negatives—an essential quality for medical diagnostics where accurate and sensitive detection is critical

The synergy between hardware capabilities and algorithmic sophistication is indicative of the trajectory that medical imaging technology is taking, moving towards more accurate, efficient, and scalable diagnostic solutions. The ability to distinguish PE from COVID-19-related lung abnormalities could significantly streamline the diagnostic process, reducing the cognitive load on radiologists and potentially decreasing the time to treatment for patients with PE.

The promising outcomes of this study, and a cross-disciplinary team of experts, emphasize the transformative potential of advanced deep-learning models like YOLOv8 in medical imaging and diagnostics. By achieving high precision and recall in PE detection, we provide valuable insights into the deployment of AI-assisted tools in healthcare, paving the path for ongoing research and innovation. This collaborative initiative marks a significant step towards leveraging technology to enhance patient diagnosis and outcomes in the complex field of medical imaging.

Our findings align with those reported by Soffer et al. [8], who achieved a mean Average Precision (mAP) of 0.65 using a similar dataset but different AI methodologies. In contrast, our model's mAP of 0.683 demonstrates a slight improvement, likely due to the advanced YOLOv8 architecture. Additionally, Alami et al. [3] focused on traditional machine learning techniques and reported an mAP of 0.55, highlighting the superior performance of deep learning approaches in medical imaging. However, the study is limited by its relatively small, single-institution dataset, which may introduce biases and affect generalizability. Future research should validate the model across diverse clinical settings and larger patient cohorts to confirm its robustness and applicability in varied real-world scenarios.

5. Conclusions

In conclusion, the implications of this study are multifaceted, demonstrating not only the feasibility but also the efficacy of employing advanced deep-learning models in the medical imaging domain. It paves the way for future research into the development of AI-driven diagnostic tools, with the ultimate goal of enhancing patient outcomes through timely and accurate diagnosis.

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