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Prodromos KAPLANIS, PhD (Biophys.), Senior Medical Physicist
Scopus ID: 6505920036
e-mail: pakaplanis@gmail.com
Nicosia General Hospital, Nicosia, Cyprus

HOW TO PREPARE FOR AI IN MEDICAL PHYSICS

By increasing diagnostic precision, streamlining treatment regimens, and boosting patient outcomes, the incorporation of Artificial Intelligence (AI) into medical physics holds the potential to completely transform the healthcare industry. This short article examines the most recent developments and uses of artificial intelligence (AI) technologies, emphasizing on Imaging, Therapy, and Quality Assurance. As far as imaging is concerned the article elaborates mainly on the applications of AI in CT, MRI, and PET images, but also ultrasound, mammography, and radiography. Therapy is one field that needs AI more than any other, as this article explains. Finally the applications of AI in Quality Assurance, are excellent tools for the Medical Physicist (MP), and the reasons for this, are explained. Whether or not there are any risks associated with the clinical application of AI-based tools is examined and which risks these might be. Challenges and ethical considerations, which according to many researchers are of the utmost importance, are also examined briefly.

K e y w o r d s : *medical physics, artificial intelligence, imaging, therapy, quality assurance.*

Introduction

Artificial intelligence (AI) is changing many industries and completely changing how humans interact with technology. Fundamentally, artificial intelligence is the creation of computer programs that can carry out operations that would normally need human intelligence. This covers the ability to solve problems, make decisions, comprehend language, and even perceive visual stimuli. It's critical to realize that Artificial Intelligence (AI) is a broad term that covers a variety of technologies, including robots, machine learning, neural networks, and natural language processing.

One can understand artificial intelligence's significant influence on our daily lives and its potential to spur innovation in industries like healthcare, banking, and transportation by delving into the meaning of the term. One needs only to examine the rise of AI in any field, in Radiology for instance, and will instantly see the tremendous rise of its applications. Vision Research Reports in 2022 have predicted that by 2030 AI in Radiology Market will reach the amazing figure of 517 million USD, as shown in Fig. 1 below. Artificial intelligence is laying the groundwork for a more intelligent and productive future through systems like intelligent assistants, automated customer support, and sophisticated data analysis.

One widely used definition of AI, is that it is a field of computer science that focuses on developing computers that can carry out tasks that typically require human intelligence. In other words Artificial Intelligence, is the process of creating models and algorithms that let computers identify patterns, learn from data, and make judgements. This field includes several subfields, such as natural language processing, which enables machines to comprehend and produce human language, and machine learning, which allows systems to become more proficient via experience.

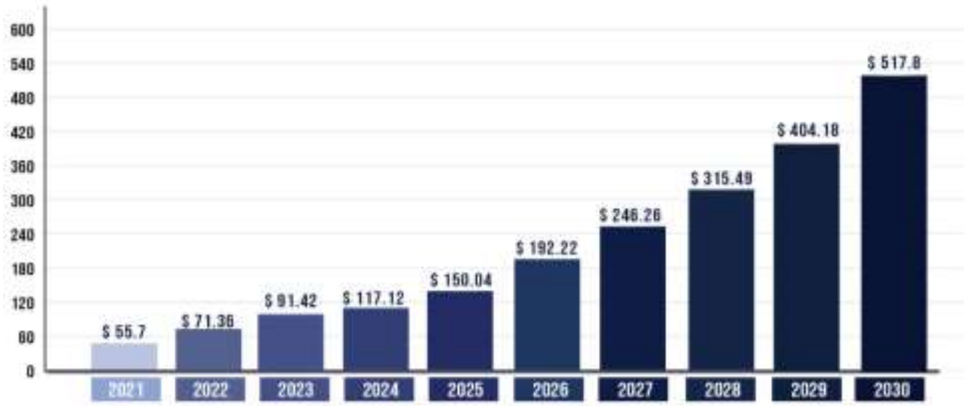

Fig. 1. Radiology Market Size 2021 to 2030 in USD, (Vision Research Reports, 2022)

Medical Physics is undergoing a revolution thanks to AI, which has the unmatched potential to improve diagnosis and treatment by analyzing enormous volumes of data. Clinically qualified Medical Physicists (CQMPs) will be essential in guaranteeing the safe and efficient application of AI-based technologies as they continue to gain popularity in the medical field.

Applications of ai in medical physics. ***Imaging.*** The primary goal of applying AI and Machine Learning (ML) to imaging is to assist medical professionals in making disease diagnoses. One of the earliest uses of these new methods in the field of imaging is computer-aided diagnosis (CAD), which integrates machine learning classifiers that are trained to discriminate between lesions and healthy tissue (Avanzo et al., 2021). When ML was used to combine Computer Tomography (CT) textural data, lung CT results showed a high degree of accuracy in differentiating between invasive and less invasive lesions and malignant lesions.

By extracting many image features-up to a few hundred or thousands – quantitative analysis of radiological images – mainly CT, Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET) images, but also ultrasound, mammography, and radiography – can be combined with ML classifiers to create prognostic and predictive models in the relatively new field of radiomics.

To shape lesions or organs, deep learning algorithms can directly learn the structure labelling of each picture voxel through a process known as semantic segmentation. PET-CT hybrid imaging has shown that U-net, one of the most widely used Depp Learning (DL) architectures for image segmentation, can automatically distinguish between lung tumours and lung parenchyma. The advantages of DL versus ML are shown in Fig. 2 below.

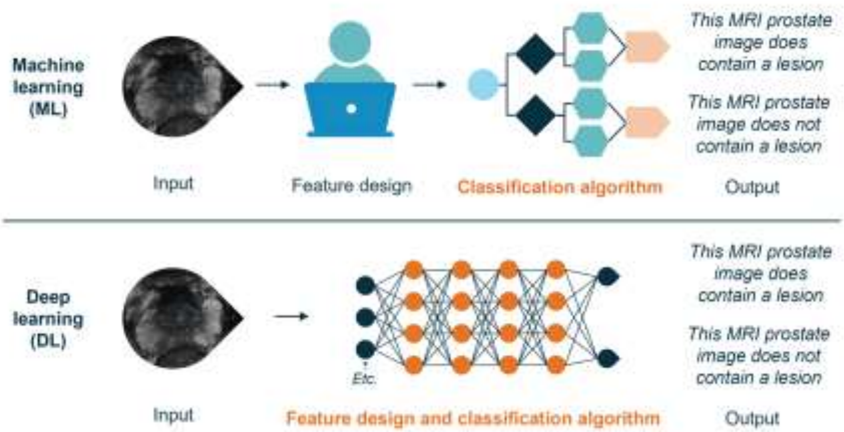

Fig. 2. Machine learning requires manual feature designing before the training of the algorithm can start. Deep learning combines feature extraction and the training of the algorithm using a neural network (Fortunati, 2022)

Patients' dose estimation is essential to the optimisation of clinical imaging protocols because it enables the dose to be matched with image quality. Dose to the patient can be automatically determined by DL in CT, Single-Photon Emission Computed Tomography (SPECT), and PET. Skin dosage estimate using DL has been proposed in interventional radiology. ML could be used to identify exams that hold potential for dose reduction by adjusting the acquisition parameters, as well as predict the volumetric computed tomography dose index (CTDIvol) in chest CT based on scan patient metrics (scanner, study description, protocol, patient age, gender, and water-equivalent diameter (DW)).

Improving image quality is another essential component of patient dose optimization since it permits dosage reduction while maintaining the same level of quality. By incorporating AI algorithms into imaging technologies, patient dose can be decreased while also increasing imaging quality. DL techniques have been applied to enhance the quality of PET images, lower noise levels, eliminate streak artefacts from CT scans, and provide new methods for reconstructing tomographic images with less recorded data. A generation of synthetic images, such as virtual contrast-enhanced images, stiff/deformable intramodal and multimodal image registration, and the extraction of the respiratory signal that could be used for breathing motion compensation of images are other promising applications.

AI in interventional radiology uses patient characteristics and picture texture to predict tumour response to transarterial chemotherapy embolisation. In the future, intra-procedural fluoroscopy and high-resolution preoperative magnetic resonance imaging could be superimposed using real-time registration DL algorithms. This would help minimise damage to nearby structures and guide doctors during catheter manipulation for the purpose of estimating ablation margins.

As far as interventional cardiology is concrned new research shows AI-based automated quantitative coronary angiography (AI-QCA) holds promise for accurate analysis of heart disease, as shown in Fig. 3 below.

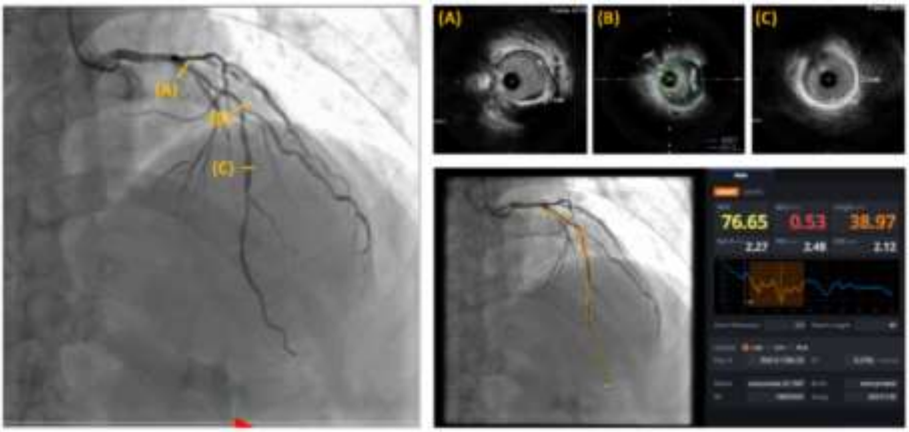

Fig. 3. A representative case in which artificial intelligence-based quantitative coronary angiography (AI-QCA) showed a good correlation with intravascular ultrasound (IVUS) observation (DAIC, 2023)
(DRD: distal reference diameter; %DS: percent diameter stenosis; LAD: left anterior descending artery; LCX: left circumflex artery; MLD: minimal luminal diameter; PRD: proximal reference diameter; RCA: right coronary artery; Ref.D: reference diameter)

AI has the potential to identify progress or recurrence at an early stage in longitudinal investigations by detecting tiny changes between images throughout treatment follow-up. AI can assist the specialist in diagnosing ocular problems like age-related macular degeneration, diabetic retinopathy, and others in the imaging fields of ophthalmic imaging, such as fundus digital photography and optical coherence tomography. Other fields of study include rheumatology and cardiology, which have a lengthy history of using AI applications to study and detect rheumatological symptoms, bone erosions, and cartilage loss.

AI is now widely used for tumor identification, subtyping, grading, staging, and prognostic prediction. This is mostly because of the advancement of computer vision algorithms and digital pathology, which was made possible by the emergence of whole-slide scanners. Proteomics and genomes may be combined in pathological diagnostics in the big-data era. A novel field called "spatial metabolomics" uses mass spectrometry and other imaging techniques to measure the distribution of molecules, including medicines, lipids, and metabolites, within bodily structures. Each pixel is represented by its mass spectrum. This technique appears interesting for the use of AI because it is characterised by a significant amount of high dimensional data, including overlapping and noisy chemical signals. Future AI applications could also concentrate on computer vision, which deals with digital picture feature and object recognition, and virtual assistants, which use speech recognition in radiology, neuroradiology, and other fields. AI-generated data could improve the operator's view of the operating room environment through augmented reality.

Therapy. Machine Learning can be helpful for several tasks during the complete radiation treatment process, beginning with selecting the best radiation strategy, such as selecting contrast between photons and protons. Targets and organs at risk in radiation can be automatically segmented by a Convolutional Neural Network (CNN). ML-based auto-planning aims to reduce inter-user variability and improve quality and efficiency by simulating the iterative plan design, evaluation, and modifications made by skilled operators.

In order to establish achievable dose constraints or dose distributions that can be used to benchmark the quality of plans, knowledge-based approaches make use of a large database of previous treatment plans-up to thousands – to establish associations between geometric and dosimetric parameters from a selection of prior plans. For brachytherapy, ML-based autoplanning was also created. To expedite the process of determining the optimal dose distribution from the patient image, DL can forecast the dose distribution from radiation therapy treatment. ML was used to forecast intraoperative radiation dose in vivo and brachytherapy dose.

Dosomics, the use of radiomics or DL to analyse the dose distribution and then adjust it into a biologically effective dose to take into account various fractionations, has been studied recently for its potential to forecast radiation therapy adverse effects. Cone-beam CT (CBCT) scans obtained for image-guidance of radiation treatment can also be subjected to radiomics, which makes these scans valuable for data mining. A significant issue with radiation therapy is the patient's changing anatomy throughout treatment, which may lead to unintended dose adjustments. Rearranging the course of treatment is necessary in this instance. ML is able to recognise notable anatomical changes in patients during radiation therapy and forecast which patients will benefit from Adaptive Radiation Therapy (ART). A model classifier is depicted in Fig. 4 below, which uses imaging to distinguish between benign and malignant breast tumors. A recursive feature elimination and reduction method was used after many radiomic characteristics were first computed and the highly correlated features, the zero and near-zero variance features, were removed. Eleven features are identified as being at the saturation point by the model performance shown above. The blue curve (right) depicts the model's error function across the number of features, whereas the red curve (left) shows accuracy versus feature count. Using eleven imaging features in this case results in good accuracy and minimizes the error function.

Eventually, sensitive/resistant tumour sub-volumes that require a greater (or lower) dose may be detected using data from radiomics voxel-based analyses. This will allow for dose painting based on a "Radiomic Target Volume" (RTV). Radiometabolic therapy using sealed (microspheres, etc.) or unsealed (radiopharmaceuticals) sources is becoming more and more significant in nuclear medicine. By taking into consideration the architecture, activity distribution, tissue density, and planning of the patient, AI can enhance dosimetry by anticipating treatment response, delivering the maximum dose to the target organ while sparing vital organs. The robustness of dosomic techniques has been investigated through methodological investigations.

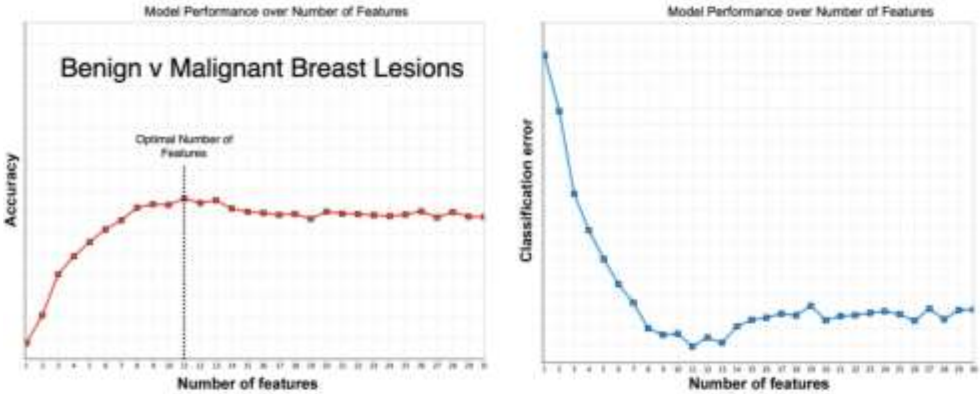

Fig. 4. Feature selection for radiomics

Quality Assurance. The International Organisation for Standardisation defines Quality Assurance (QA) as a system that guarantees the quality of a certain process, service, or product. The system's quality is determined by how well it satisfies requirements, which are needs or expectations that are expressed but typically implied or required, preventing errors and flaws. A product or process's description, measurement, analysis, improvement, and control are all achieved through the use of quality controls, or Quality Control (QC), tests. QC processes are utilised in radiological sciences to ensure that diagnostic and therapeutic devices and procedures, as well as clinician support systems, are verified and monitored. AI has the potential to automate quality control QC tasks that would be too time-consuming and impractical to complete by hand on a regular basis.

Without human assistance, AI quality control systems might be trained to become more accurate over time and create new tests. A major portion of the MP's work is quality assurance of radiotherapy (RT), which aims to prevent radiological incidents and incorrect radiation dosage administration. Several ML techniques have been investigated to forecast treatment plan errors in order to automate plan chart checks. To find faults in prostate plans, a K-means clustering algorithm was used to learn from previous plans.

Risks associated with the clinical application of ai-based tools. AI is a hot issue for clinical study and discussion, although there aren't many implemented AI-based solutions in use in clinics overall. There are several obstacles to overcome in the clinical, technological, safety, ethical, privacy, and regulatory domains when implementing AI in healthcare. If these issues are not resolved, they may act as a roadblock to more widely used AI in healthcare settings. Possible reasons for the caution around broader implementation of AI-based applications include the real risks of unintended and negative consequences, the lack of diversity, standardization, and harmonization of data elements used to develop and train the AI-based models, the difficulties in their clinical implementation, validation, and quality assurance, the legal and ethical issues, and the lack of specialized education and training of the involved health professionals, (IAEA, 2023).

Challenges and ethical considerations. Although integrating AI into medical physics has revolutionary advantages, there are drawbacks and moral dilemmas to be resolved. Critical issues that require close consideration include preserving patient data confidentiality and privacy, mitigating algorithmic bias, and preserving transparency in AI decision-making procedures. The responsible and long-term application of AI in healthcare requires striking a balance between innovation and moral issues (Bollmann et al., 2024).

Discussion and conclusions

AI has the potential to broaden Medical Physicists' areas of expertise by extracting even more data to enhance medical care, and Medical Physicists are prepared to embrace the AI revolution. However, the Medical Physicists' expertise will be necessary for the safe and successful use of AI, particularly in the field of radiological sciences, and their participation in the multidisciplinary AI team is vital.

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Продромос КАПЛАНІС, д-р філософії (біофіз.), ст. мед. фізик
Scopus ID: 6505920036
e-mail: pakaplanis@gmail.com
Загальна лікарня Нікосії, Нікосія, Республіка Кіпр

ЯК ПІДГОТУВАТИСЯ ДО ВИКОРИСТАННЯ ШТУЧНОГО ІНТЕЛЕКТУ В МЕДИЧНІЙ ФІЗИЦІ

Впровадження штучного інтелекту (ШІ) у медичної фізики може повністю змінити сферу охорони здоров'я завдяки підвищенню діагностичної точності, оптимізації схем лікування та покращенню результатів лікування пацієнтів. Проаналізовано найновіші розробки та застосування технологій штучного інтелекту

з наданням особливого значення саме візуалізації, терапії та забезпеченню якості. Щодо застосування ШІ у візуалізації здебільшого розглянуто технології КТ, МРТ і ПЕТ, ультразвукової інтроскопії, мамографії та рентгенографії. Пояснено, чому терапія – це сфера, яка найбільше потребує ШІ. Показано, що застосування ШІ в забезпеченні якості є чудовим інструментом для медичного фізика (МФ). Вивчено існування ризиків, що пов'язані з клінічним застосуванням інструментів на основі ШІ. Коротко розглянуто виклики та міркування щодо етичності, які, на думку багатьох дослідників, надзвичайно важливі.

Ключові слова: ***медична фізика, штучний інтелект, візуалізація, терапія, забезпечення якості.***

Член програмного комітету П. Капланіс заявляє про відсутність конфлікту інтересів та невтручання в процес оцінювання цієї статті відповідно до міжнародних стандартів публікаційної етики. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

The member of the Program committee P. Kaplanis declares no conflict of interest and has not interfered in the evaluation process of this article, in accordance with international publication ethics standards. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; in the decision to publish the results.