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The Role of Machine and Deep Learning in Modern Medical Physics

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Artificial intelligence (AI) is thought by some to be the most fundamental transformation in our lives since the industrial revolution [1] with perhaps its greatest expected impact to be in medicine [2]. With the rapid increase in patient-specific information and computing power, there has been tremendous interest in the medical physics community to deploy machine/deep learning (ML/DL) algorithms in a wide range of diagnostic and therapeutic radiological applications to automate laborious processes, improve workflow, and aid physicians in their pursuit to realize precision medicine. This includes but is not limited to applications in computer-aided detection, classification, and diagnosis in radiology and auto-contouring, treatment planning, response modelling (radiomics, radiogenomics), image-guidance, motion tracking, and quality assurance in radiation oncology. Despite this interest by medical physicists, ML/DL algorithms have been surrounded by misunderstandings about their strengths, weaknesses and best practices for training, validation, and testing that have limited their practical clinical implementation in day-to-day clinical and medical physics operations.

Since the inception of modern AI and ML in the late 1950s, medical physicists have been at the forefront of their development and application in medicine, including decision-support systems in radiology and treatment planning in radiotherapy, ushering this new era of *AI-assisted medicine* [3]. However, this new era also presents unique technical

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challenges for the effective, ethical and safe application of AI in the various areas of medicine. With their computational skills and domain knowledge, medical physicists are in a unique position to address these challenges as investigators and end users, enabling appropriate and safe implementation of these transformative technologies.

The aim of this special issue is to provide a summary of the latest advances in ML/DL technologies. The 8 especially commissioned articles provide examples of ML/DL applications in radiation medicine, highlighting their advantages and future potential to improve clinical practice, while also addressing their limitations, challenges, and open questions for future research. The special issue will also address common pitfalls encountered when applying these powerful data-analytic tools to medical physics problems and suggest tips for successful implementation and reporting of ML/DL results.

The special issue starts with an "Introduction to Machine and Deep Learning for Medical Physicists," by Cui *et al.* [4]. The article aims to provide a *practical tutorial to ML/DL* with discussion of basic aspects involved in ML/DL model building, data preparation, model training, and model validation. The article also presents worked-out examples of common medical physics AI applications with associated python code, to enable interested readers to acquire hands-on ML/DL skills as a steppingstone towards pursuing their own original work.

Auto contouring has been a daunting challenge in radiology and radiotherapy, and Seo *et al.* [5] provide a comprehensive review on "Biomedical Image Segmentation: An Overview of Technical Aspects and Introduction to State-of-Art Applications." In the article, they discuss how ML/DL can enable efficient and accurate segmentation of medical images. It also contrasts classical ML and DL approaches with pros and cons of each approach and how to address pertained issues.

Quality assurance (QA) is crucial for proper clinical application of radiotherapy to cancer. Kalet *et al.* [6] present on "Quality Assurance Tasks and Tools: The Many Roles of Machine Learning." The article discusses how ML can improve radiotherapy safety by automating patient-specific and machine QA tasks. At the same time, they also discuss how applying QA principles to safe application of ML in radiotherapy.

Outcome modelling is key for successful precision medicine. In "Machine Learning for Radiation Outcome Modeling and Prediction," Luo *et al*. [7] highlight intriguing aspects of modelling tumor response and normal-tissue complication probability, including the trade-offs between complexity and interpretability and between structured and unstructured data.

Quantitative image analysis, also known as *radiomics*, has been an active area of research in medical imaging. In "Machine and Deep Learning Methods for Radiomics," Avanzo *et al.* [8] review diverse clinical applications, research opportunities, and available computation platforms for radiomics. It also reviews the many powerful open-source and commercial platforms currently available for radiomics analysis.

Genomics has the potential to revolutionize modern medicine, including radiotherapy, but remains a work in progress. In "Genomics models in radiotherapy: from mechanistic to machine learning," Kang *et al.* [9] examines the evolution of *radiogenomics*. The article thoroughly reviews radiogenomics, modelling frameworks, and efforts towards realizing genomics-guided radiotherapy. The article discusses radiogenomic biomarker development for clinical assays of normal- and tumor-tissue radiosensitivity. and how radiogenomic signatures can be incorporated into more accurate predictive models.

Computer-Aided Diagnosis (CAD) is one of the earliest success stories of AI in medicine. In "Computer-Aided Diagnosis in the Era of Deep Learning," Chan *et al.* [10] trace its rich history and discuss its current role. The article also discusses the potential and challenges in developing DL-based CAD tools, the pitfalls and lessons learned from CAD in screening mammography, and considerations involved future clinical implementation of CAD.

The generalization from CAD to general *Clinical Decision Support systems* (CDSS) is presented by Bermego *et al.* [11] in their paper, "Artificial intelligence based Clinical Decision Support in Modern Medical Physics: Selection, Acceptance, Commissioning and Quality Assurance." The article describes a rigorous selection process to help identify the CDSS that best fits the preferences and requirements of the local site and acceptance testing to ensure that the selected CDSS fulfils the defined specifications and the safety requirements. The commissioning process can prepare the CDSS for safe clinical use. Finally, the articles reviews continuing QA practices for ensuring that the specified level of CDSS performance is maintained and that any deviations are promptly identified and addressed.

It is our hope that this special issue will serve as a practical guide for medical physicists interested in deploying machine/deep learning technologies in medicine, radiology, or radiation oncology and as a useful resource for illustrating the current status and future prospects of this technology.

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