ARTIFICIAL INTELLIGENCE (AI) – BOON OR BANE FOR MEDICAL PHYSICS PROFESSION?

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I. INTRODUCTION

The term AI was first coined by John McCarthy in 1956 as the science of engineering and making intelligent machines. However, early works in AI had not achieved many breakthroughs due to the limited computing power. It was only in the last decade that AI research in healthcare and medicine had started to show promising results and practical applications, from facial recognition to fully automatic detection, and even finding new biomarkers for diagnosis and follow up. It has been recognised as both a productive and disruptive force in healthcare. In particular, radiology, radiotherapy and pathology are the three medical specialities that saw the more prominent AI role and therefore has impacted directly the medical physicist's profession. Some medical physicists may view AI as a threat to the future of the medical physics profession.

Artificial Intelligence (AI) is rapidly transforming various domains, including healthcare, and medical physics is no exception. The integration of AI in medical physics is poised to revolutionize the field by enhancing diagnostic accuracy, streamlining treatment planning, and improving patient care where it is revolutionizing medical physics primarily in radiation therapy, diagnostic imaging, and nuclear medicine. As AI gains prominence, medical physicists face the dual challenge of integrating AI-driven advancements while ensuring accuracy, safety, and ethical compliance. In this article, I am trying to explore the potential of AI to transform medical physics, focusing on its applications, challenges, and future directions and whether AI is going to be boon or bane for the medical physics profession, examining its impact on clinical practices, research, professional roles, and ethical considerations.

If AI is used with its full understanding with taking care of its limitations and pitfalls, AI can benefit medical physics in numerous ways, enhancing efficiency, accuracy, and patient safety. For example, in radiation therapy, AI-driven treatment planning systems optimize dose distribution, reducing planning time and improving precision. In diagnostic imaging, AI-powered tools assist in segmenting tumour regions in MRI and CT scans, minimizing human error. AI also supports quality assurance by predicting equipment failures before they occur, ensuring continuous and safe operation. Additionally, AI accelerates research by analysing vast datasets to identify trends, leading to improved patient-specific treatment plans and predictive modelling for better healthcare outcomes. However, AI has pitfalls and limitations that must be addressed. One significant issue is the risk of algorithmic bias, where AI models trained on limited or unrepresentative datasets may produce inaccurate or inconsistent results. Additionally, AI systems may lack transparency, ensuring continuous and safe operation. making it difficult for medical physicists to interpret and validate AI-generated recommendations. Over-reliance on AI could also lead to skill degradation among medical professionals, reducing their ability to assess and correct potential errors. Moreover, regulatory and implementation challenges persist, as AI systems require thorough validation and continuous monitoring to ensure their reliability. Addressing these limitations is crucial to integrating AI safely and effectively in medical physics practice.

Now, I will focus on areas where AI can be applied efficiently and effectively by Medical Physicist in clinical practice.

II. RADIATION THERAPY (RT)

In radiotherapy, AI is used to enhance the accuracy of treatment planning by reducing human intervention and improving plan quality. AI platforms can predict the radiation sensitivity of tumours before treatment starts, helping determine the optimal dose for patients. Additionally, AI can assist in image-guided radiotherapy by generating synthetic CT images from MRI data, reducing the need for additional CT scans and lowering radiation exposure.

a. Treatment Planning

- AI can automate and optimize treatment planning for radiation therapy, especially in Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), and Stereotactic Body Radiation Therapy (SBRT).
- Machine learning models can predict optimal dose distributions, organ-at-risk (OAR) sparing, and treatment plan quality assurance.
- AI-based tools such as deep learning algorithms help in auto-segmentation of tumours and

OARs in CT and MRI images, reducing manual workload and increasing output.

b. Quality Assurance (QA)

- AI-driven predictive analytics can help detect treatment errors before delivery of treatment giving a chance to correct.
- AI-enhanced gamma analysis and dose verification tools improve patient safety and treatment accuracy.
- Automated machine learning models can predict and correct equipment deviations before failure/breakdown/malfunction.

c. Adaptive Radiotherapy

- AI can help in daily image-guided adaptive radiotherapy (IGRT) by predicting anatomical changes during fractionated treatments and suggesting real-time plan adjustments.
- Deep learning models analyse imaging data to improve dose recalculations and motion management.

III. MEDICAL IMAGING AND DIAGNOSIS

AI plays a crucial role in automating routine tasks in medical imaging, such as image processing, quality control, and data management. It can automatically segment and label structures in medical images, reducing the time and effort required by healthcare providers. AI algorithms can analyse medical images to identify patterns and abnormalities that may not be visible to the human eye, aiding in more accurate and timely diagnoses.

a. Image Processing and Enhancement

- AI can improve image quality and reduce noise in MRI, CT, and PET scans.
- AI-based denoising algorithms help in low-dose CT (LDCT), reducing radiation exposure to patients while maintaining image quality.
- Super-resolution techniques using AI enhance imaging details without increasing scanning time.

b. Automated Image Segmentation

- AI can segment tumours, organs, and lesions with high precision, reducing inter-observer variability.
- Deep learning-based segmentation models are widely used in brain, lung, breast, and prostate cancer imaging.

c. AI-Assisted Diagnosis

- AI can detect early signs of cancer, neurological diseases, and fractures from imaging scans at pixel level before it is visualised by clinicians on image without AI.
- Deep learning models in MRI and CT scans help identify even very minute abnormalities that radiologists might miss without AI.

d. Radiomics and Predictive Analytics

- AI can extract and analyse imaging biomarkers for tumour characterization, choose treatment options, treatment response prediction, and prognosis estimation.
- Radiomics, combined with machine learning, can help differentiate between benign and malignant tumours without pathological or biochemical sampling.

IV. RADIATION SAFETY AND DOSIMETRY

a. AI-Driven Dosimetry

- AI models can estimate radiation dose distributions in patients undergoing radiotherapy [dose painting/mapping] or diagnostic imaging.
- AI-based Monte Carlo simulations can improve dose calculations for complex cases more precisely.

b. Radiation Protection and Monitoring

- AI-enhanced sensors and wearables devices can monitor radiation exposure in real time for medical staff and the opportunity to take preventive measures by modifying work practice immediately, if need be.
- AI-powered systems can predict radiation leakage or errors in shielding design in radiotherapy rooms so that corrective measures can be taken in a timely manner.

c. AI in Brachytherapy

- AI can optimize dose planning for high-dose-rate (HDR) and low-dose-rate (LDR) brachytherapy, ensuring precise dose delivery, maximising dose in tumour and sparing OAR effectively.
- AI-based algorithms can automatically adjust dwell times and catheter placements for better outcomes of the treatment.

V. AI IN PROTON AND HEAVY ION THERAPY

- AI is used for beam range prediction, ensuring precise proton stopping points thereby overcoming the uncertainty in RBE and dose deposition.
- AI-driven models optimize treatment plans to account for uncertainties in proton range and dose distribution.

VI. AI IN NUCLEAR MEDICINE AND PET IMAGING

a. AI in SPECT and PET Imaging

- AI algorithms improve image reconstruction and reduce scan times in PET and SPECT imaging thereby increasing efficiency and efficacy.
- AI-based noise reduction allows for low-dose radiotracer imaging thereby minimizing patient radiation exposure.

b. AI in Radiopharmaceutical Production

- AI can assist in optimizing radioisotope production, predicting radiopharmaceutical decay, and enhancing supply chain management efficiently.

VII. AI IN MEDICAL PHYSICS EDUCATION AND RESEARCH

a. AI for Medical Physics Training

- AI-based simulations, e-tutorials can train medical physicists in radiotherapy planning, quality control, and safety assessments.
- Virtual AI tutors and decision-support systems enhance learning efficiency.
- One of the IMPW2025 webinar on 7 May 2025 is focusing on AI in Medical physics education and training.

b. AI for Research and Development

- AI models accelerate Monte Carlo simulations for dosimetry calculations.
- Machine learning aids in predicting treatment responses and improving personalized precision medicine approaches.

VIII. AI FOR WORKFLOW AUTOMATION AND DECISION SUPPORT

a. AI in Hospital Workflow Optimization

- AI helps in automating scheduling for radiation therapy, reducing patient waiting times.
- AI-powered systems optimize machine usage, staffing, and patient throughput more efficiently and economically.

b. AI for Clinical Decision Support

- AI-based predictive models assist oncologists in selecting optimal treatment strategies.
- AI-driven algorithms provide evidence-based recommendations for patient management.

IX. AI IN GUIDED SURGERIES AND ROBOTICS

- AI is integrated with robotic-assisted radiation therapy (Cyberknife, MR-Linac, PET-Linac) for real-time tumour tracking.
- AI-driven robotic systems enhance precision in biopsy procedures and brachytherapy seed placement.

X. BENEFITS OF AI IN MEDICAL PHYSICS

a. Enhanced Accuracy and Efficiency

AI significantly reduces human error in tasks such as image segmentation, treatment planning, and dose calculations. Machine learning models improve precision in detecting anomalies in imaging, leading to earlier and more accurate diagnosis.

b. Improved Workflow and Productivity

AI automates repetitive tasks, allowing medical physicists to focus more on complex decision-making and patient-specific treatments. Automated treatment planning reduces planning time, making radiation therapy more efficient.

c. Personalized Treatment and Adaptive Radiotherapy

AI-driven models analyse patient-specific characteristics, allowing personalized treatment regimens. Adaptive radiotherapy uses AI to adjust treatment in real time, enhancing efficacy and minimizing side effects.

d. Advancements in Research and Innovation

AI accelerates research by analysing large datasets, identifying patterns, and predicting patient responses to treatments. This facilitates innovation in treatment protocols, imaging techniques, and predictive analytics.

e. Enhanced Quality Assurance and Safety

AI-powered quality control ensures equipment calibration, detects anomalies, and predicts failures in medical devices. This helps medical physicists to enhance patient safety and reduce treatment-related errors.

It is now clear that AI is transforming Medical Physics by improving the accuracy of radiation therapy, imaging, dosimetry, and radiation safety. With continued advancements, AI will enhance patient outcomes, reduce human errors, and optimize clinical workflows, making Medical Physics more efficient and effective, however there are challenges which need to be addressed.

XI. CHALLENGES AND FUTURE PERSPECTIVES

While AI has immense potential in Medical Physics, there are many pitfalls and challenges which need to be tackled

XII. POTENTIAL HARM AND CHALLENGES OF AI IN MEDICAL PHYSICS

a. Risk of over-reliance and loss of expertise:

Over-dependence on AI may lead to skill degradation among medical physicists, reducing their ability to critically evaluate AI-generated outputs. This could be detrimental in cases where AI fails or produces incorrect results. Medical Physicists needs to alert and avoid becoming slaves of machine/ AI but to remain the master of it.

b. Job displacement and changing roles:

Automation of routine tasks might reduce the demand for traditional roles in medical physics, leading to concerns about job displacement. However, AI also creates opportunities for new roles focused on AI oversight and algorithm development. AI will not completely replace medical physicists but medical physicists who fail to embrace and acquire skills in AI will definitely be replaced.

c. Data bias, generalizability issues and limited patient diversity:

Models trained on datasets lacking diversity may not generalize well across different populations. AI models are only as good as the data they are trained on. Bias in training datasets can lead to inaccuracies in treatment recommendations, potentially compromising patient outcomes. Therefore, generating own data and updating/validating the software tuned to country/region is necessary. It’s like garbage in, garbage out.

d. Regulatory and Implementation Barriers:

Ensuring the accuracy and reliability of AI algorithms is crucial. AI integration in medical physics requires stringent validation, regulatory approvals, and continuous monitoring. Standardizing AI practices across institutions remains a complex challenge.

e. Data privacy and security:

Patient privacy and safety are paramount. AI systems must be developed and used responsibly to maintain trust in healthcare and must comply with data privacy regulations of the country.

f. Interpretability of AI decisions:

AI-driven medical decisions need to be explainable to clinicians and clinicians need to be trained and acquainted with the system.

g. Integration with existing workflows:

AI tools must seamlessly fit into ongoing clinical practice and adaptation to future issues.

h. Informed Consent:

Patients must be informed about the use of AI in their care, including how their data is used and the potential risks and benefits of AI-driven decisions. This ensures that patients have autonomy over their healthcare choices.

i. Accountability and Transparency:

AI models can be complex and difficult to interpret, making it challenging to hold anyone accountable for their decisions. Ensuring transparency in AI decision-making processes is essential to build trust and ensure accountability.

j. Education and Training:

Medical physicists need updated education and training to effectively integrate AI into their practice

XIII. FUTURE DIRECTIONS

Rather than replacing medical physicists, AI should be viewed as a collaborative tool that enhances their capabilities. The future of AI in medical physics is promising for medical physics and lies in integrating AI responsibly, ensuring ongoing research aimed at addressing current challenges:

- **Integration with Emerging Technologies:** Combining AI with other technologies like big data analytics and machine learning will further enhance its capabilities in medical physics.

- **Development of Guidelines:** Establishing clear guidelines for the use of AI in medical physics is essential to ensure safe and effective implementation.
- **Continuous Education:** Medical physicists must acquire AI literacy to understand, validate, and oversee AI-driven systems. Regular updates in education and training programs will be necessary to keep medical physicists proficient in AI technologies.
- **Human-AI Collaboration:** AI should assist, not replace, expert judgment, with physicists providing oversight for AI recommendations.
- **Ethical and Transparent AI Development:** AI algorithms must be explainable, unbiased, and continuously refined based on real-world data.
- **Regulatory Adaptation:** Policies should evolve to ensure AI's safe and effective use in medical physics.

XIV. CONCLUSION

AI has the potential to revolutionize the practice of medical physics by improving diagnostic accuracy, enhancing treatment planning, and optimizing patient care. AI presents both opportunities and challenges for the medical physics profession. While it enhances accuracy, efficiency, and innovation, concerns regarding expertise retention, ethics, and job displacement must be addressed. By adopting a balanced approach—leveraging AI's strengths while maintaining human oversight—medical physicists can harness AI's potential to improve patient outcomes and advance the field. The future lies in collaboration, ensuring AI serves as an augmentation rather than a replacement for human expertise in medical physics and ongoing research and development are poised to address these issues, paving the way for a future where AI is integral to medical physics. Now, almost every one of you will agrees with me that AI is essential and will only continue to play increasing roles in medical physics and it is you will make use of this revolutionary technology as a boon for medical physics professionals.

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