Medical physics 3.0: A renewed model for practicing medical physics in clinical imaging

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ABSTRACT

Inspired by the principles of Medical Physics 3.0, this paper frames a new model of clinical physics practice, anchored to clinical realities, clinical priorities, and advanced physics. The model is based on the conviction that the physicist is vested with the expertise and the responsibility to ensure each patient gets the optimum imaging exam towards the best clinical outcome. Key expectations and activities are encapsulated into 12 areas: scientific perspective, quality and safety assurance, regulatory compliance, technology assessment, use optimization, performance monitoring, technology acquisition, technology commissioning, vendor cooperation, translational practice, research consultancy, and technology education. The paper further highlights key challenges to effective clinical physics practice of increased regulatory compliance, technology assessment, use optimization, performance monitoring, technology acquisition, technology commissioning, vendor cooperation, to the discovery of mysterious x-rays. Roentgen deservedly received the first Nobel prize in physics, as his discovery started the very field of medical imaging. From the first medical images taken only months after Roentgen’s discovery, medical imaging quickly proved a technological breakthrough of modern medicine. Today, non-invasive interrogation of the human body inform the care of nearly every patient. Our medical images are able to freeze the respiratory and heart motions, delineate three-dimension structures of the disease in fine details, and reveal the physiological processes of the human body. Images non-invasively ascertain not only the presence of a disease but also its progression to guide its treatment.

Medical imaging owes much of its success to physics, which has continually advanced the frontiers of its technologies. Likewise, physics has informed imaging practice by providing the needed definitions and oversight of its effectiveness and safety. However, this clinical contribution has been very modest, as many physicists, coming from a core scientific background, do not find clinical practice scientifically as intriguing. However, this is a profound misconception. Physics is inherently present not in the workings of an imaging technology but also in the body that it images. As such, physicists have many opportunities to apply their science to the clinical care of patients, harnessing the very insights that were foundational to the discipline and technology of medical imaging in the first place. We can argue that this is in fact not only an opportunity but actually a responsibility: The ultimate purpose of any medical profession is patient care, immediately or eventually. Medicine’s aspirations of enhanced personalization, consistency, and safety needs medical physicists’ unique fusion of scientific mind and medical relevance. For example, they are uniquely equipped to understand how measurements made on an image can best reflect the biological reality and thus be trusted to inform a patient’s care.

1. Introduction

Physics has been known as one of the crown jewels of human intelligence. Albert Einstein and Marie Currie have iconified not only the sheer brilliance of human mind but also physics’s ability to shape human culture and welfare. That is no less evident than when an physics experiment in November 1895, keenly observed and meticulously documented by German Physicist Wilhelm Roentgen, unexpectedly led to the discovery of mysterious “x” rays. Roentgen deservedly received the first Nobel prize in physics, as his discovery started the very field of medical imaging. From the first medical images taken only months after Roentgen’s discovery, medical imaging quickly proved a technological breakthrough of modern medicine. Today, non-invasive interrogation of the human body inform the care of nearly every patient. Our medical images are able to freeze the respiratory and heart motions, delineate three-dimension structures of the disease in fine details, and reveal the physiological processes of the human body. Images non-invasively ascertain not only the presence of a disease but also its progression to guide its treatment.

2. Key roles of clinical physics

Patients stand to benefit from the quality patient imaging that is only possible through the contribution of clinical physicists. But specifically how? There are 12 interrelated activities through which physics and physicists can and should contribute to the clinical practice of medical imaging. These are summarized in Table 1 and detailed below.

2.1. Scientific perspective

Medicine is changing. Recent years have witnessed a drive towards evidence-based medicine [1], seeking the clinical practice to be intentionally-informed by science. Additional emphases on comparative effectiveness, meaningful use, and value [2] have further put extra scrutiny on the actual, as opposed to presumed, utility of clinical practice [3].
numerical reflection.

These moves call for an enhanced scientific approach in medicine. Physics is a foundational scientific discipline integral to imaging. Physicians are trained and skilled in the language and methods of science, where they are explicitly conditioned to critically and repeatedly scrutinize their claims, assumptions, and models based on objective quantitative data and disciplinary norms. These numerical and analytical competencies uniquely equip physicists with perspective and knowledge to contribute to evidence-based and data-informed practices, quantitative imaging, and value-based care.

2.2. Quality and safety assurance

Medical imaging devices are complex and diverse in type, make, and model, and technical parameters. This, combined with the diversity in patients, human operators, and stakeholders of varying (sometimes competing) interests, creates variability in the quality of care within and across practices. This variability is not insignificant and has a cost. A recent report from the National Academy of Medicine [5] notes that most people will experience at least one diagnostic error in their lifetime, and 10% of patient deaths and 6–17% hospital adverse events are due to diagnostic errors. Medical imaging, being largely a diagnostic procedure, contributes to these statistics. Presence of physicists in the clinic tackles this challenge. By overseeing the setup and use of the equipment and imaging processes, the physicists offer an essential scrutiny of the operation to improve the quality, safety, and consistency of the practice, and thus minimize the likelihood of mishaps.

2.3. Regulatory compliance

Towards the assurance of quality and safety, regulatory compliance and adherence to professional guidelines and standards offer a “scaffolding” for quality practice. This compliance is a first order of business for quality operation. And it is highly facilitated by active engagement of imaging physicists, yet another strong justification for the presence of physicists in the clinic. However, due to their reactive tendencies, regulations and guidelines are by necessity always a step behind current clinical needs, realities, and opportunities. They are at best only a
safeguard against previously-identified issues. Thus, while the compliance in the current clinical physics practice is necessary, it is not enough.

2.4. Technology assessment

The modern practice of clinical physics, as encouraged through the Medical Physics 3.0 paradigm [6], is based on three elements (Fig. 1). First among them is technology assessment. Generally done through acceptance testing and quality control, devices are characterized to ensure adherence to vendor claims and regulatory guidelines. This essential task should extend from the assurance of specifications to assessments that reflect the expected clinical outcome [6]. For example, expanding conventional physics quantities of resolution or noise to detection or estimation indices can more relevantly reflect the capability of the technology to deliver an objective clinical goal. This is a shift from assessing a technology in terms of its physical specifications to its clinical performance.

2.5. Use optimization

Having ensured the intrinsic capability of the technology, the physics practice should use those attributes to ascertain how the technology can best be deployed in clinical service to ensure the desired image quality and safety for a given patient, i.e., personalized care (Fig. 1). This speaks to the targeted use of the technology so that a desired clinical outcome can be achieved [7-8]. A significant component of this activity is protocol development and optimization, addressing specific clinical needs including indication-specific image quality, contrast agent administration, adjustments for patient attributes, and dose optimization. Having devised optimum imaging protocols, clinical physicists should further be vested with the responsibility of ensuring the proper protocols are loaded and used, the imaging process is efficiently carried out, and individual exam customizations are ordained by a priori standard operating procedures.

2.6. Performance monitoring

The combination of technology assessment and prospective optimization stated above should ideally provide actual optimum image quality and safety. In reality, however, there are many factors that influence the actual outcome of an image acquisition beyond those anticipated from the assessment and optimization processes. These include unforeseen conditions, technological variability, and human factors. This motivates a troubleshooting mandate for clinical physicists. But troubleshooting, as commonly practiced, is sporadic and only address the most noticeable problems. Latest technologies in dose and performance monitoring enable physicists to systematically analyze the output of the imaging examinations [9-12] (Fig. 1). These analyses can ensure that the actual output of the imaging technology matches expectations in terms of quality and safety surrogates, diagnostic performance [13], and consistency of the operation. Variabilities can be understood and mitigated. Physicists, with their content expertise and numerical training, are uniquely qualified to undertake such analyses.

2.7. Technology acquisition

Medical imaging has been and remains subject to perpetual and highly-desired technological innovations. This is evident across all modalities; recent examples include wireless digital technology and cone-beam multi-dimensional imaging in radiography and fluoroscopy, 3D imaging in mammography, advanced reconstructions and spectral imaging in CT, new pulse sequences and functional applications in MRI, 3D imaging and elastography in ultrasonography, theranostics in nuclear imaging, and AI-based processing and classification across all modalities. New technologies and features often have physics foundations. Clinical physicists, with their strong technical background, can advise for wise and evidence-based selection of a technology and choices across its array of features. They can offer technical comparison of choices, predict how the new features may deliver their claim, and devise how they can best be integrated within the existing practice.

2.8. Technology commissioning

The diversity of technology across a practice is natural considering the evolving nature of the field. New innovations and asynchronous life cycle of systems in use within a clinical facility create a challenge for consistency in image quality and dose. Introducing a new technology into a practice often offers as much opportunity to improve the practice as to degrade it. Better technologies cannot be assured to provide superior performance. Case in point is the transition from film to digital radiography which led to a marked degradation of consistency across practice due to diverse, unoptimized processing capabilities. Physics commissioning is essential to ensure that well-intentioned and well-designed technologies do not compromise the consistency of care. It helps manage and minimize the influence of technological variability; i.e., “commodifying” new and varied technologies so that imaging becomes more reflective of the patient condition and less that of the technology.

2.9. Vendor cooperation

Considering the high innovation in the technology used in medical imaging today, the best practices are often enabled by a strong connection with the manufacturers. The best use of the technology requires understanding it well. Physicists, by expertise, tend to be best positioned to understand technological foundations of the new offerings. They are often ideal individuals from the institution to liaise with the vendor, understand the nuances, and communicate and contextualize them for their clinical team. Having a combined clinical and technical perspective, they can also offer advice to manufacturers on how to best condition their products for effective use in the clinic, and facilitate partnership to develop and advance new applications.

2.10. Translational practice

A direct benefit of having the scientific mind and the quantitative reasoning of the physicist is the opportunity to improve the practice through quality improvements, aka clinical scholarship, a scholarship oriented not only towards generalizable knowledge but clinical translation. As examples, such scholarship may include task-based optimization of a processing method, optimizing needed imaging series, or AI-based characterization of image artifacts. They may also include challenging elements of the clinical practice which by themselves might not be considered “physics,” but nonetheless can be benefited by a scientific perspective. Examples include optimizing workflows across a clinic, the limits and role of AI technologies in the clinic, or devising key performance indicators (KPIs). For any of these projects, the scholarship is oriented towards workable a clinical implementation.

2.11. Research consultancy

Research has been a quintessential component of medical physics, and it is expected to remain so for foreseeable future. This research has brought forth many innovations to medicine in terms of new technologies, applications, and methodologies. But once these resources are added to clinical practice, there is yet one more role that medical physicists are making in their conditioning and use. Limiting this contribution here to clinical practice only, clinical physicists can be catalysts and enablers for academic research. They can serve this function even though their primary mission is and should be clinical. Nonetheless, this is of primary relevance to academic healthcare institutions with a research mission. Meaningful and impactful research in
medical imaging often requires an understanding of the imaging system deeper than that needed in clinical practice. Clinical physicists, by the virtue of their expertise are best positioned to provide the consultancy and sometimes crucial resources to enable such academic research.

2.12. Technology education

Technologies that are brought forth and enabled by medical physicists are not trivial. They are anchored to advanced research and development enabled by years of graduate education. Such content cannot be assumed easily comprehensible by other health professionals whose mission and focus is justifiably on other aspects of healthcare. This necessitates yet another mandate for clinical physicists to “translate” the medical physics science into a language and reflections that can be understood by their non-physicist colleagues. And such translation should be of such quality that it can inform the delivered care – the very purpose of any clinical practice.

Imagining physicians, tasked with the interpretation of medical images, require physics competencies. Likewise imaging technologists, tasked to image the patients, need to understand the physics aspects of the process. The needed competences for either group, customized specifically for each, fall into four areas [14]: 1) the foundations of contrast formation in a given imaging modality; 2) the technological components of image acquisition; 3) operational parameters and their influence on image quality and patient safety; and 4) how to practice imaging within the constraints, the needs of the indication, and capabilities of the technology. Physicists are uniquely qualified to provide education towards these competencies for both physicians and technologists. This contribution empowers these colleagues to be more proficient for their direct mandate: direct patient care.

3. Challenges to effective clinical physics practice

Quality practice of physics in the clinic within the multi-faceted workspace that is detailed above can be challenging. The challenges are not insurmountable, as exemplified by seasoned physicists and exemplary physics practices. They have been able to find practical ways to use their expertise to inform and improve clinical care. To do so, the first step is to understand these challenges and then devise mindful and practical means to mitigate them. Such understanding not only makes a practicing clinical physicist more proficient but also enables better education for the next generation of clinical physicists.

3.1. Increased scope of competency

The first challenge is simply the magnitude of knowledge that a clinical physicist is expected to master to practice effectively in the clinic. This is not just traditional medical physics knowledge, which by itself is ever expanding given the progressive nature of medical imaging. But further, a clinical medical physicist needs to have enough foundational clinical and associated peripheral knowledge to be able understand key practice issues and to communicate across diverse clinical disciplines. New topics that require expanded mastery include, but are not limited to, data science and artificial intelligence, process engineering, multi-factorial optimization, bio-informatics, radiomics, and radiogenomics.

Added to this list are the so-called “soft” skills of leadership and communication that have been essential for good clinical practice. Good communication skills are needed for leading and working within clinical teams and for communicating with patients in matters related to the technical aspects of their care. A clinical physicist should perpetually seek wisdom and mentorship in balancing the breadth and depth of the needed hard and soft competencies for good practice.

3.2. Balancing rigor and relevance

Clinical imaging physicists are both scientists and care providers. As scientists they have been trained to seek perfection and seek reality, yet as practitioners they need to be equally aware of practical limitations of care delivery. The science that a clinical physicist pursues is highly applied – not oriented towards generalizable knowledge necessarily – but oriented towards benefitting individual patients. Maintaining this balance of scientific rigor and clinical relevance is a challenge. A perfect solution is often out of reach due to lack of time, money, or external support, but a solution is needed nonetheless. Navigating this landscape requires mindfulness, mentorship, and wisdom.

3.3. Managing quantitative surrogates

Clinical imaging physics seeks to assess and optimize the quality and safety of the practice towards the assumed eventual improvement of the care outcome. However, a direct relationship between our measures and
the outcome is very difficult to ascertain given the diversity across the patients and confounding effects within the care process. Short of having direct measures of outcome, which are subject to influences beyond the preveiw of imaging, we are left with surrogates (Fig. 2). Within this space, measures that are more directly related to the quality and safety of care for the actual patient are most relevant. For example, compared to CTDI and noise, the more progressive metrics of organ dose and detectability index are more closely related to the radiation burden and quality of a CT exam. However, more progressive surrogates are also more prone to estimation errors. Ascertaining what metric offers the best balance between its associated benefit (relevance) and limitation (uncertainty) is a delicate choice that needs to be made on a situation by situation basis. The best surrogate is the one that can best be used to improve the practice.

3.4. Integrating principle- and data-informed approaches

Most of physics is based on methodical principles and their logical conclusions. However, those can never be assumed to lead to error-free understandings, thus the reason for experiments. We can apply the principles of medical physics to ascertain an image outcome. However, like an experiment, it is the clinical image that is the actual evidence for the presumed outcome. Image data can give us highly-relevant information about the effectiveness of our assumptions. A clinical physicist should be able to seamlessly integrate the principle-informed approaches of medical physics with data-informed methods to ascertain and aim towards the best practice. The current focus of healthcare on machine-learning and artificial intelligence provides amble resources towards that goal. Physicists should navigate and use these resources and be a catalyst in their effective use in clinical care [15].

4. Conclusions

Medical imaging and interpretation continue to provide unprecedented value to patient care. Innovative technologies offer enhanced opportunities for high-quality imaging care, but also more complexity and variability. In this landscape of enhanced but diverse imaging options, optimized use of the technology cannot be assumed. This, in tandem with new clinical mandates of evidence-based and value-based practice, requires utmost rigor in the effective use of technology. Medical physics enables innovative precision care through the targeted clinical application of physical sciences. This role is unique and essential for quality patient care. A renewed clinical physics, inspired by the Medical Physics 3.0 vision of fostering human health through physics, can extend beyond compliance testing towards intentional evidence-based and value-based use of the technology to best serve clinical care.

Acknowledgment

This paper is an extension of a book chapter by the same author [16]. The author gratefully acknowledges inspirational conversations with Carl Ravin, Tom Grist, Erik Paulson, members of the Duke Clinical Imaging Physics Group, and members of the AAPM MP3.0 committee.

References