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Why physics in medicine?☆

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ABSTRACT

Despite its crucial role in the development of new medical imaging technologies, in clinical practice, physics has primarily been involved in technical evaluation of technologies. However, this narrow role is no longer adequate. New trajectories in medicine call for a stronger role for physics in the clinic. The movement towards evidence-based, quantitative, and value-based medicine requires physicists to play a more integral role in delivering innovative precision care through the intentional clinical application of physical sciences. There are three aspects of this clinical role: technology assessment based on metrics as they relate to expected clinical performance, optimized use of technologies for patient-centered clinical outcomes, and retrospective analysis of imaging operations to ensure attainment of expectations in terms of quality and variability. These tasks fuel the drive towards high-quality, consistent practice of medical imaging that is patient-centered, evidence-based, and safe. While this particular article focuses on imaging, this trajectory and paradigm is equally applicable to the multitudes of the applications of physics in medicine.

Radiology and physics have always had a symbiotic relationship. Beginning on November 8, 1895 when the German Physicist and first physics Nobel laureate Wilhelm Roentgen discovered the mysterious “x” rays, physics has had a central role in the development and advancement of Radiology. While the science of medical physics and the clinical practice of radiologic interpretation have followed separate professional trajectories, they remain tightly connected. Over the decades, medical physics has enabled continuous advances in imaging and its safe and effective use. At the same time, medical physics has drawn its meaning and raison d'être from clinical radiology. The clinical practice of radiology rests on a physics foundation, while medical physics exists to serve clinical interpretation. The relationship between radiology and physics has thus been mutual and essential for both disciplines for the overall goal of medicine: fostering human health. In the current healthcare landscape of enhanced and diverse imaging options, optimized and evidence-based use of the technology cannot be assumed. Physics has great potential to move beyond compliance and safety testing towards intentional evidence-based use of the technology to serve clinical care.

1. Cultural trajectories in medicine call for a close relationship

In recent years we have seen a drive towards evidence-based medicine [1], ensuring that clinical practice is informed by science. Physics, as a foundational scientific discipline, can naturally contribute to this goal within the practice of radiology. Likewise, the current emphasis on comparative effectiveness and meaningful use puts extra scrutiny on the actual, as opposed to presumed, utility of technology and processes [2–5]. This highlights the need for a scientific approach towards practice, again with an obvious role for physics. In line with these moves, medicine is also seeing a slow shift towards quantification, using biometrics that personalize the care of the patient in numerical terms [6]. This provides for better evidence-based practice for both diagnostic and interventional care. Again, physics is a discipline grounded in mathematics and analytics with direct potential for the practice of quantitative imaging. Finally, the mantra of value-based medicine [7] highlights new priorities for safety, benefit, consistency, stewardship, and ethics. To practice value-based care, the value needs to be quantified, which again brings forth the need for numerical competencies, such as physics can provide. These trends in medicine call for a closer exchange between physics and radiology.

Concurrent with the trajectories of evidence-based, quantitative, and value-based medicine is the significant promise of artificial intelligence (AI) in medicine [8]. In the future, many routine tasks performed today by Radiologists and Medical Physicists may be delegated to computational systems that are able to offer intelligent characterizations of images and imaging systems. While this will certainly be disruptive to the practice of radiology and medical physics, it is best recognized as an opportunity. AI is definitely coming to medical imaging, but if implemented well it would not replace Radiologists or

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Medical Physicists, but become a tool for our collective use. This will create yet another context for collaboration between Radiologists and Physicists. The characterizations AI can provide may presumably be superior to those of an individual practitioner, because they are based on large aggregates of information representing the best of imaging physics and clinical practice. Curation of such aggregate data across the heterogeneity of imaging technologies is a monumental task. Given their skills in numerical analysis and clinical integration, Physicists can significantly aid in the curation of aggregate data, in the use of imaging models to facilitate data mining, and thus in the meaningful implementation of AI technology into radiology practice. Likewise, using their skills in clinical informatics and image interpretation, Radiologists are uniquely qualified to curate imaging data and insure their quality and integrity for use in data mining.

2. New technologies call for a close relationship

Medical imaging has had the enviable status of maintaining perpetual technological innovation throughout its history. Every time we feel settled with a particular technology, a newer one is around the corner. Let us highlight just a few recent developments, in no particular order: Computed tomography has seen major advances in the use of statistical reconstructions, novel geometries, and spectral imaging. Mammography is experiencing a strong shift towards tomosynthesis and computer-aided diagnosis. Magnetic resonance imaging is undergoing major development in new pulse sequences, advanced reconstruction, and MR quantification. Nuclear imaging is moving towards hybrid imaging and molecular precision. Radiography and fluoroscopy are witnessing a significant move towards wireless digital technology and cone-beam multi-dimensional imaging. Ultrasonic imaging is moving towards three-dimensional imaging, elastography, and new contrast-based acquisitions. And medical displays are showing a shift towards the use of color, multi-dimensional rendition, and portable monitors. What are the implications of these advances in the practice? How can we ensure that well-intentioned and well-designed technologies are used effectually for the improvement of patient care without compromising the consistency of care? These are questions that can only be answered using an integrated strategy that includes both physics and radiology.

3. Radiologic competency calls for medical physics

Radiologists are not just physicians: they are physicians with special added expertise in interpreting medical images. To do so effectively and accurately, Radiologists need not only be specialized medical competency, but also technical competency. This technical competency often distinguishes a Radiologist from other physicians that use images for their practice. It consists of understanding 1) the foundations of contrast formation in a given imaging modality; 2) the technological components that enable the acquisition of an image; 3) the modality's operational parameters and their influence on image quality and patient safety; and 4) how to practice imaging within the constraints of the imaging modality and the needs of the indication [9]. These elements are cornerstones of the physics competency expected from Radiologists by the American Board of Radiology. The experts of this domain are Medical Physicists, who can provide training for junior practitioners in which their technical expertise is matched with the effective use of adult learning methods and with an understanding of the different norms and culture of the two disciplines (a challenge for any interdisciplinary exchange).

4. New physics for new technologies and new priorities

Current radiologic practice is based heavily on assuring compliance with regulations and guidelines. This is necessary, but it is not enough. The newest guidelines highlight this limitation [10,11]. Physics is most relevant to the extent it seeks to address clinical needs and limitations. Regulations, by necessity, are always a step behind clinical opportunities, needs, and realities. The cultural and technological changes highlighted above require a change in practice. New technologies and applications will not yield superior results unless their implementation is optimized. While change is inevitable, practice, by definition, tends to be resistant to change. Physics can play an essential role in the effective implementation of new technologies and applications consistent with the overarching new priorities of medicine (evidence, effectiveness, quantification, and value). Towards that aim, new physics practices aim to devise and implement new metrics that are reflective of the performance of new technologies as well as the expected clinical outcome [12]. For example, characterizing the performance of a system in terms of detection or estimation indices (as opposed to the more conventional physics quantities of resolution or noise alone) can directly speak to the capability of the technology to deliver an objective clinical goal. In this way, physics can offer a quantification that is evidence-based and that can enable the meaningful comparison and optimization of new technologies and applications.

5. Modern medical physics in practice: assessment, optimization, analytics

The modern practice of clinical physics is based on three elements (Fig. 1). One primary goal of clinical physics practice is technology assessment based on metrics that reflect the attributes of those technologies and relate to expected clinical outcomes. Towards that goal, the characterization of devices to ensure their adherence to vendor claims or regulatory guidelines is necessary but not enough; we must move from compliance-based to performance-based quality assurance. Having ensured the intrinsic capability of the technology, as its second goal, the physics practice uses 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. This speaks to the optimized use of the technology so that a desired clinical outcome can be targeted [13–18]. A significant component of this activity is protocol development and optimization, addressing specific clinical needs including dose reduction, adjustments for patient attributes, indication-specific image quality, and contrast agent administration.

The combination of these two goals of technology assessment and prospective optimization should ideally provide actual optimum image quality and safety. In reality, however, there are many factors that influence the actual outcome of the image acquisition including unforeseen conditions, technological variability, and human factors. Thus a third goal of medical physics is to analyze the output of the imaging operation to ensure adherence to targeted expectations [19–26]. Using aggregate curated data sets such as those currently used in dose monitoring, this analysis can ensure that the actual output of the imaging technology matches its promise, capturing both its inherent capability and its optimum use. This type of analysis can target both the quality and the consistency of the operation, helping to better understand and mitigate variability in the clinical operation, and to quantify the actual impact of new technologies. Medical Physicists, due to their content expertise and numerical training, are uniquely qualified to undertake this data science-based analysis.

6. Models of effective radiology and physics integration

The call for a deeper investment in medical physics towards enhancing patient care comes at the time when radiologic interpretation duties consume even more time than before and NIH funding concerns and economic pressures in hospitals potentially pull physics and radiology apart. Many institutions are either not aware of this potential, or opt for the minimum of regulatory compliance. Some institutions, however, seem able to manage these pressures and effectively harness the value of physics in their practice. How? What are the best working

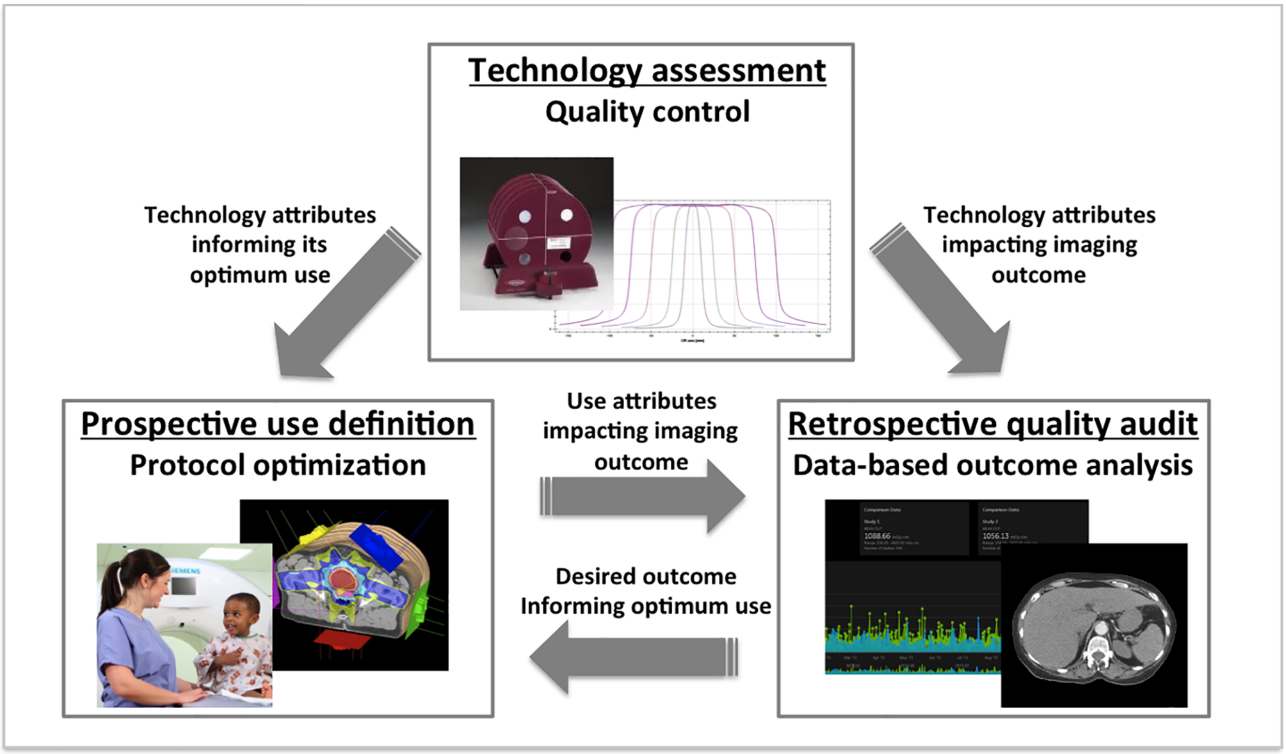

Fig. 1. The three major components of the new practice of medical physics. Attributes and assessment of technology (represented in the upper square) inform its optimum use (left square), and the two of them impact image outcome (right square). Outcome analysis conversely informs the optimum use of the technology.

models that can enable better concordance and integration of radiology and physics?

There are differences even among best practices, but all institutions that have managed to integrate their radiology and physics practices towards improved patient care share certain common attributes: 1) There is high degree of consciousness at the leadership of the institution about the historical track record and value of physics. 2) Exemplary Physicists have been able to go beyond the realm of theoretical possibility and demonstrate the value of physics within the clinical practice in practical ways. 3) The complementary nature of the expertise of the Radiologist and the Physicist is recognized and respected. A feature of civilized society is its ability to use professionals for its specialized needs. Such is the case for institutions that defer to Physicists on issues that need physics solutions. 4) Funding for physics services is justified based on added value. At one institution, 2% of radiology revenue is allocated to radiological physics based on the track record that the investment has paid more than its share in ensuring the quality and safety of the operation, wise investment in equipment acquisition and replacement, and minimum liability for near misses. 5) In an era in which patients have choices, these institutions recognize that the distinction of a high-quality and high-safety operation can lead to greater market-share of healthcare services.

In summary, medical imaging and interpretation continue to provide unprecedented value to healthcare. Innovative technologies offer enhanced opportunities for high-quality imaging care. These new clinical realities, however, require the utmost rigor in the effective use of technology in the drive towards high-quality, consistent practice of medical imaging that is patient-centered, evidence-based, and safe. Medical physics can advance us towards innovative precision care through the targeted clinical application of physical sciences. In the move towards innovative precision care, physics and radiology more than ever need intentional engagement and a shared arena of operation. The Radiologist-Physicist partnership is mutual and impactful—it empowers both disciplines in the service of human health, and can have a tangible impact on the quality and safety of imaging operations. More than ever, it is also necessary, in order to harness the breakneck speed of technological innovations, to characterize and optimize their use and operation, and to enact value-based and evidence-based medicine.

7. Take-home points

- Promising technological innovations enable improved care only thru effective use within the heterogeneous context of clinical practice.
- Patient-centered, evidence-based, and safe practice of medical imaging assumes and requires optimized and consistent use of the technology.
- With their deep understanding of underlying science, physicists enable innovative precision care through relevant assessment, optimization, and retrospective practice analysis of the surrogates of imaging quality and safety.
- Given their skills in numerical analysis and clinical integration, physicists can significantly aid in the curation of quality aggregate data and in effective data mining thru the use of imaging models, facilitating the meaningful implementation of AI into radiology.
- The radiologist-physicist partnership empowers both disciplines, enabling value-based and evidence-based medicine in the service of human health.

Conflict of interest

Dr. Samei reports grants from Siemens, non-financial support from GE Healthcare, other from medInt Holdings, LLC outside the submitted work. Dr. Grist reports relationship with GE Healthcare, Bracco Diagnostics, Siemens, Hologic, Change Healthcare, Elucent, and Histosonics outside the submitted work.

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