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Editorial

The importance of accurate treatment planning, delivery, and dose verification

In recent years, the spectacular technological advances in radiotherapy have generated much enthusiasm.[1] Newer techniques take advantage of increased computing power and real-time imaging to provide pinpoint accuracy and dose conformity. The most widely adopted of the new techniques is undoubtedly intensity-modulated radiation therapy (IMRT) and variations thereof. Described as "perhaps the most significant technical advances in radiation therapy since the linear accelerator", IMRT gives us the ability to deliver highly conformal nonconvex dose distributions to the target with astonishing precision.[2] Compared to 3D-CRT, IMRT offers many advantages, particular better dose distribution in concave target volumes and lower doses to organs at risk (OAR).[3,4] IMRT is surely an immense technological leap forward, though not without certain risks.

All radiotherapy involves risk because even a small error in treatment planning, delivery, or dosimetry can lead to negative consequences. This is because the human body is a complex organism and tumors are often located in close proximity to sensitive normal tissues and critical organs. For this reason, novel technologies that allow us to treat and cure patients with minimal adverse effects are very welcome. Unfortunately, the newer techniques are highly complex, thus increasing the potential for error. All modern radiation therapy techniques are heavily reliant not only on technology, but also on input from human experts: the radiation oncologist must locate and contour the target area as accurately as possible; then, the medical physicist needs to design an optimal plan which will deliver the required dose while sparing healthy tissue; finally, the technologist must make sure that the patient is correctly positioned before treatment begins. All of these myriad steps are susceptible to errors that may occur due to poor safety or training procedures, software flaws, or calibration errors.[5] Indeed, a very critical New York Times investigation[6] reported on the sometimes devastating consequences of such errors (though it must be said that most of the mistakes reported by the NY Times could have been prevented by better quality control, and were not due to the technology per se). Quality assurance (QA) has long been an integral part of the field of radiation oncology, although interest has increased sharply in recent years in response to the safety challenges presented by novel technologies and automated radiotherapy techniques.[7,8]

The aim of the present editorial is not to focus on human mistakes related to poor quality control, but rather to examine the importance of detecting, minimizing, and eliminating the (usually) small errors in planning, patient set-up, and delivery that can result in harmful irradiation outside of the target area. IMRT and other advanced techniques (image-guided RT, stereotactic radiosurgery, etc.) represent an entirely new paradigm that requires extensive knowledge and understanding of the latest imaging systems, setup uncertainties, radiobiological response of healthy tissues, three-dimensional (3D) dose calculation and optimization, variable intensity beam delivery, and internal organ motion.[9] In an age in which steep dose gradients are commonplace, it is imperative that the radiation be delivered as precisely as possible.

One way to ensure accurate delivery is to account for internal organ motion. This requires real-time imaging that allows for the radiation beam to be continually adjusted and aligned with the tumor. When performed successfully, this method can improve accuracy and reduce doses to surrounding tissues, thereby increasing local control while reducing toxicity.[10] In recent years, interest in understanding and addressing organ motion during radiotherapy has increased dramatically. Organ motion presents a complex challenge to planning and delivery of radiotherapy, and it is particularly demanding when it comes to complex treatments such as IMRT.

The inherent complexity in planning and delivery of IMRT requires a comprehensive QA program to prevent errors. At present, QA in IMRT involves QA of the treatment planning and delivery system, in addition to patient-specific quality control. IMRT QA is similar to that used for conventional 3D conformal radiation therapy, with the main difference being that the number of parameters requiring verification is much greater for IMRT: complex calculations are required to control beam intensity and each IMRT field often includes many small irregular off-axis fields which provide more conformal dose coverage but also increase complexity. As a result, dose

calculation and delivery accuracy must be validated for both treatment planning and delivery, and the overall accuracy of irradiation is highly dependent on uncertainties in both the planning and delivery processes.[11] Fortunately, the problems with providing appropriate QA for IMRT have been thoroughly studied and presented in numerous publications. Methodologies and tools that support safe and accurate IMRT have been developed and checked, and organizations such as the ESTRO and ASTRO publish guides to assist with these procedures.[12,13]

In an ideal world, integrated, dedicated planning and delivery systems would be available to all. However, such systems are expensive and often cost-prohibitive. However, in a interesting paper[14] published in the journal *Radiology & Oncology*, Das et al. describe how they were able to create a fully electronic IMRT QA process in a network of independent treatment planning, record and verify, and delivery systems. These authors were able to successfully implement a paperless and filmless IMRT QA process. These authors found that their system allowed them to ensure proper dose delivery to patients. They conclude that for centers without an integrated planning, verifying, and delivery system, a completely electronic IMRT QA process is still possible.

At our journal, Reports of Practical Oncology and Radiotherapy, we believe that areas related to accuracy in planning, delivery, and verification are sometimes underappreciated. As a result, we frequently publish articles that address these crucial aspects of quality control and accuracy in radiotherapy. For example, one recent article investigated the use of an electronic portal imaging device (EPID) for quality assurance in Volumetric Modulated Arc Therapy (VMAT).[15] The authors emphasize the importance of an accurate and reproducible patient set-up as absolutely essential to precise delivery of fractionated radiotherapy, which, in this case, they achieved through the use of the AlignRT software in breast cancer patients.[16]

Another recent study[17] evaluated an anatomy-based method of IMRT verification. The authors explain that during a proper execution of dynamic multileaf collimated (dMCL) treatment plans, the radiation dose accumulated by tissue is often widely different than expected. According to these authors, conventional dosimetric QA procedures give only a partial picture of the quality of IMRT treatment because their purely quantitative measurements are confined to the detector's total area rather than the actually irradiated volume. They developed a dynamic plan verification procedure that allows for visualization of potential dose distribution anomalies and which can identify exactly which tissue these anomalies occur. The authors created their own proprietary software (GammaEval) to evaluate over 150 dose distribution maps. This novel method permits precise identification of deviations between predicted and acquired dose distributions (registered by portal and film).

Perhaps the main concern about IMRT is "leakage" of the dose to healthy surrounding tissues. This is particularly relevant in high-risk areas with many OARs located nearby, as occurs in gynecological cancers. One approach to minimizing this problem can be seen in a recent study that compared 6 MV vs. 15 MV photon energy plans for IMRT in cervix cancer.[18] The authors found that the 6 MV plan resulted in comparable coverage of the planning target volume (PTV) with better OAR sparing. Another notable study compared IMRT and Cyberknife treatment plans for localized prostate cancer.[19] In that study, the authors reported that both systems are good at creating highly conformal volumetric dose distributions, with good OAR sparing.

Discrepancies between estimated and delivered doses continue to present some difficulties. To address this issue, Sardari et al. used a Geant4-based software application to simulate the absorbed dose distribution in a water phantom, finding that measured and calculated dose values showed good agreement with this technique.[20] Similarly, Slosarec et al. reported on a procedure for the use of EPID for in vivo dosimetry with the RapidArc technique.[21] Numerous methods can be used for dose verification. One recent study evaluated the influence of different types of detectors on measured modulated dose distributions. These authors reported that radiographic film can be used for the dosimetry of compensated high energy photon beams.[22] Another study evaluated dosimetry in a 320 detector row CT scanner unit.[23] These are but a few examples of the unending search to improve planning so that pretreatment calculations better reflect actual doses delivered. Undoubtedly, this is an area that will continue to receive attention.

Another important obstacle in improving and standardizing IMRT techniques is the large variability among institutions in terms of IMRT dose prescription, recording, and delivery. This heterogeneity makes it difficult to compare clinical outcomes for IMRT. Das et al.[24] recently compared 5 different centers and found that 46% of the patients received a maximum dose that was more than 10% higher than the prescribed dose, while 63% of the patients received a dose that was more than 10% lower than the prescribed dose. Moreover, the recorded isocenter dose varied from prescription for evaluated tumor localizations and treatment planning systems. They conclude that substantial variation in the prescribed and delivered doses exists among medical institutions, and they call for national and/or international guidelines for dose prescription, planning, and reporting for IMRT.

In this era of dose escalation, complex technology, and advanced computer algorithms, sometimes it is important to take a step back and be creative in our approach to improving treatments. Recently, one group of researchers presented their innovative approach to reducing toxicity to OARs in prostate cancer.[25] In this 24 patient study, two treatment plans (Tomotherapy) were performed for each patient: one in the supine and one in the prone position. These authors found that prone position was associated with lower doses in OARs, especially in the rectum. They conclude that, in patients irradiated to prostate and seminal vesicles, the prone position may spare the rectum and bladder.

Throughout this editorial, the point has been made that present day radiotherapy is extraordinarily complex and therefore requires great diligence to assure accurate delivery in accordance with the treatment plan. Although much progress has been made, much remains to be done. At Reports of Practical Oncology and Radiotherapy, we are doing our best to publish relevant papers on this critical subject. Although I agree with Chung et al.[26] that "treatment planning and delivery in radiation therapy will be never perfect", I would hasten to add that we must continue doing our best to make it so.

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Julian Malicki[a,b,*]

[a] *Medical Physics Department, Greater Poland Cancer Centre, Poznan, Poland*

[b] *Electroradiology Department, University of Medical Sciences, Poznan, Poland*

[*] Correspondence address: Medical Physics Department, Greater Poland Cancer Centre, Poznan, Poland.
E-mail address: julian.malicki@wco.pl

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