Transmission detectors are safe and the future for patient-specific QA in radiation therapy

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OVERVIEW

Real-time radiation dose monitoring during treatment delivery is highly desired for quality assurance purposes but has been hampered in its clinical implementation due to various technical challenges. Recent advances in transmission detector technology offer a potential solution for real-time dosimetric measurements of treatment delivery. While some are optimistic about the clinical adoption of transmission detector technology for enhancing the safety of radiation therapy, others have some significant concerns about using transmission detectors for dosimetric measurements. This is the premise debated in this month’s Point/Counterpoint.

Arguing for the Proposition is Dharanipathy Rangaraj, Ph.D. Dr. Rangaraj obtained his Ph.D. in Nuclear Engineering from the University of Missouri in 2004 followed by postdoctoral research at Indiana University Purdue University Indianapolis and completed medical physics residency at Washington University School of Medicine in 2007. He served as Director of Medical Physics at Baylor Scott and White Health between 2012 and 2016. He currently serves as Clinical Associate Professor of Radiation Oncology at Texas Tech University, Lubbock, Texas. His major research interest is the application of technology to solve quality and safety problems in radiation therapy.

Arguing against the proposition is Sridhar Yaddanapudi, Ph.D. Dr. Yaddanapudi is a Clinical Assistant Professor in the Department of Radiation Oncology at University of Iowa Health Care. He obtained his M.S. in Nuclear Engineering from University of Missouri and completed a medical physics residency at Washington University School of Medicine in 2009. He obtained his Ph.D. in Nuclear Engineering from University of Missouri in 2015. He was the chief of quality assurance service of radiation oncology at Washington University in St. Louis. His primary research interests are quality assurance and automation in radiation oncology.
FOR THE PROPOSITION: Dharanipathy Rangaraj, Ph.D.

Opening Statement

Radiation therapy is a technology-driven field. The quality, safety and, very importantly, the outcomes of radiation therapy rely heavily on the ability to deliver the radiation dose to the intended location. Over several decades, significant research and development have gone into delivery equipment (linacs, specialized devices such as multi-lead collimators (MLCs), specialized machines), delivery techniques (intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), stereotactic-body radiation therapy (SBRT)) and targeting technologies (cone-beam computed tomography (CBCT), planar imaging, surface imaging, radio frequency (RF)-based technologies) to enhance the effectiveness of radiation therapy. One of the critical areas that did not keep up with these radiation therapy technology advancements is real-time dose delivery monitoring. In simple 3D conformal and Co-60 days, the dual chamber transmission detector, called the monitor unit (MU) chamber, was considered sufficient as there was a relationship between dose and MUs.1 But there is no direct correspondence between dose and MUs for IMRT/VMAT plans as they use a larger number of MUs compared to 3D conformal plans.

Pretreatment IMRT quality assurance (QA) was introduced because of our inability to measure the dose delivered in real time.2 Vendors developed numerous ways to verify the pretreatment delivery to a phantom, primarily because the technology to verify dose delivery by direct dose measurement for every beam, every fraction, and every patient was not practical. Therefore, we started assuming that a pretreatment measurement of the dose was sufficient for the patient QA paradigm, along with machine QA and weekly chart review. In my mind, this unquestioned assumption has resulted in some severe mistreatments as reported in New York Times articles published in 2010.3,4

Real-time dose delivery measurement with electronic portal imaging devices (EPID)-based exit dosimetry has been reported by several groups, but has not been adopted for several reasons.5 The primary reason is that the detector itself is not ideal for dose measurement, especially if one needs to determine dose discrepancy during each patient’s treatment. Furthermore, identifying the source of a discrepancy, that is, dose delivery error vs setup error vs other calculation errors, is very difficult. The common sense approach for real-time dose measurement technologies should be to measure all the discrepancies separately and then combine them to determine the actual reality and eliminate any ghost errors, false positives or true negatives.

Currently, with the development of transmission detectors, it is possible to determine all delivery-related errors, while the setup and anatomical changes can be determined by the online volumetric imaging to provide dose-based quality assurance for every beam, every fraction, and every patient.6 Common sense trumps common practice and, as a field, we remain stuck in the pretreatment IMRT QA paradigm, which has shown to be the least effective in mitigating errors, yet it is still our standard practice.7

Finally, I would like to conclude with a statement from The New York Times article “identifying radiation errors can be difficult. Organ damage and radiation-induced cancer might not surface for years or decades, while underdosing is difficult to detect as there is no injury. For these reasons radiation accidents seldom results in lawsuits, a barometer of potential problems in the industry”.8 Since technologies such as transmission detectors are available and enhance the safety of our field, I have no doubt they will become the primary tool in radiation therapy departments because they are safe, effective, and make sense.

AGAINST THE PROPOSITION: Sridhar Yaddanapudi, Ph.D.

Opening Statement

The standard of treatment at many clinics currently includes IMRT and VMAT, enabling escalation of target dose while reducing dose to surrounding organs at risk. Patient-specific QA procedures are considered to be an essential component to validate these IMRT/VMAT treatment plans before treatment. There are different measurement-based procedures for dosimetric verification of IMRT/VMAT treatment plans, such as point-dose measurements utilizing ionization chambers and/or a 2D dose distribution compared with treatment plan calculated dose using films, detector arrays, or EPID.8 Transmission detector measurements are the latest technology to be used for dosimetric verification of IMRT/VMAT treatment plans.7

There are significant concerns about the use of transmission detectors for dosimetric verification of IMRT/VMAT. The detectors need to be attached to the linac head, which could lead to potential collision/clearance issues during treatment. The transmission detectors should be in direct path of the beam leading to perturbation of the fluence. The attenuation through the transmission detectors needs to be accounted for in the treatment planning system (TPS). The Radiological Physics Center (RPC) results showed that approximately 30% of institutions failed the ±5% dose difference tolerance criteria.9 The study concluded that the causes for failures include incorrect data entered into the TPS and incorrect beam modeling. Hence, trying to model the transmission detector attenuation in the TPS could lead to potential errors that might not be caught until a later time. There is also the issue of activation of the transmission detectors along with an increase in skin dose. Last but not the least, the economics cannot be ignored.

The question to be asked is “what errors would transmission-detector technology catch?”. From a Failure Mode Effects Analysis (FMEA) point of view for external beam, there seem to be more errors happening upstream in the treatment planning process. Ford et al. quantified the error-
detection effectiveness of quality control (QC) checks in radiation oncology departments.\textsuperscript{10} They showed that the most effective check was physics pretreatment plan review while the least effective check was pretreatment IMRT QA. The study concluded that EPID-based \textit{in vivo} portal dosimetry, in combination with physicist and physics plan review, could detect errors effectively. Mans et al. have shown the potential of \textit{in vivo} EPID dosimetry as an effective QC verification.\textsuperscript{11} A software-based system for the treatment plan review process can complement \textit{in vivo} EPID dosimetry to detect incidents in radiation therapy.\textsuperscript{12–14}

In conclusion, transmission detectors still have some limitations that need to be resolved before they can be considered as the future for radiation therapy. In my mind, tools such as machine log-file analysis offer an alternative and economical solution to catch most of the errors that a technology like transmission detector would if we do an FMEA study. In addition, a complementary system of software-based and EPID-based tools provide an effective method for verification of treatment plans.

Rebuttal: Dharanipathy Rangaraj, Ph.D

Safety is an investment, not a cost. We need to ask the question: how many patients can we afford to hurt? One is too many. With that philosophical position, I counter some of my colleague’s objections.

Dr. Yaddanapudi states that machines have interlocks for MLCs and other checks for beam parameters, so why would one need transmission detectors? That is precisely the point of independent quality assurance which has been corner stone of our field. Transmission detector brings in real-time delivery quality assurance data that, when coupled with CBCT setup data, will provide an accurate picture of the dose delivered to the patient on a fraction by fraction basis, which to-date we do not have in many radiation oncology clinics.

I am perplexed that mounting the transmission detector on the head of the linear accelerator would be considered an issue. Mounting the x ray tube on the gantry gave us IGRT which has improved the safety and quality of treatments enabling more precise verification of treatment delivery.\textsuperscript{15} With the adoption of transmission detectors, we will also be able to document dose delivery which will complete the quality assurance loop’s missing puzzle, the real-time dose delivery verification and assurance.

Transmission detectors have been successfully developed with low attenuation (<1%) without need for beam model changes, automated interfacing with R&V systems has enabled a seamless workflow, they have an acceptable activation level proven by FDA and linear accelerator manufacture approvals, and no loss of clearance and fit within the collision guard of the machine. In my opinion, these are challenges that, can be, and have been overcome successfully.\textsuperscript{6,7}

From an FMEA stand point, my opponent questions what additional errors will transmission detectors be able to catch. Dr. Yaddanapudi also answers his own questions by quoting that Ford et al. have shown, in a retrospective study, that \textit{in vivo} dosimetry on the first fraction would have mitigated the majority of their reported events (76% of reported events in their institute reporting system),\textsuperscript{10} proving the necessity for real-time \textit{in vivo} measurement.

Finally, Dr. Yaddanapudi brings to our attention the economics. Radiation Oncology is not yet considered a highly reliable organization when compared to other industries such as nuclear and airline, which have their utmost focus on safety technologies, redundancies, and processes. I see transmission detectors as a technology that would help our field become a highly reliable organization. Would one board an airplane with its onboard monitoring system turned off? Even knowing that there is a preflight QA (equivalent of pretreatment QA), and a post-flight QA analysis (equivalent of weekly chart checks or log-file analysis), the answer would probably be NO. Yet we assume that the dose delivery of a complex radiation treatment is acceptable, and daily measurement-based dose verification is not essential, even when such technology is available. This is our common practice, but it is not common sense in my opinion. I believe that, as a field, we will embrace a transmission detector as a “safety detector”, and it will become a critical part of every radiation oncology practice.

Rebuttal: Sridhar Yaddanapudi, Ph.D

Dr. Rangaraj makes a compelling argument about transmission detectors in his opening statement. With the current technological advancements in the field of radiation therapy, a common sense approach to determine delivery-related errors for every beam of every fraction for every patient, is highly desirable. However, I am not convinced that transmission detectors would be the future for patient-specific QA in radiation therapy.

I have to disagree with Dr. Rangaraj’s position on using EPIDs for dosimetry purposes. EPIDs have been around for almost two decades and are an attractive alternative for IMRT verification. They have a high spatial resolution and offer the advantage to perform \textit{in vivo} dosimetric measurements. Utilizing an appropriate EPID calibration technique, one can determine the dose to within 2%. Thus, a simple, efficient, and automated method for IMRT verification can be achieved with EPID dosimetry.\textsuperscript{5,16}

The New York Times errors that Dr. Rangaraj mentioned could have been identified by utilizing automated software methods. Computerized automation plays an essential role in helping us achieve higher quality and safer treatments. EPID-based \textit{in vivo} dosimetry would provide an efficient and effective QC check in radiation therapy.\textsuperscript{17} Complementing the IMRT verification with a rules-based software check for pretreatment plan review, would aid in detecting errors and effectively mitigating them.

Dr. Rangaraj states that machine delivery errors can be caught with transmission detectors. Catching these errors at the time of treatment is too late. An adoption of TG-100 methodology\textsuperscript{18} for machine QA will ensure each component of the delivery system is functioning within tolerance, so the
real-time dose verification is more of a documentation of delivery parameter variance which can be obtained from R&V systems and automated software checks.

The future of QA is not finding errors at treatment, but preventing them from reaching the patient. This can be achieved by adopting the TG-100 QA methodology, which would prevent errors from propagating through the radiotherapy workflow, so that the chance of failure at the final verification step is very rare. While transmission detector is a useful tool for dosimetric verification of IMRT/VMAT treatment plans, there is still some time before they are routinely adopted in radiation therapy clinics.

CONFLICTS OF INTEREST

Dr. Rangaraj is a founder and President of Crux Quality Solutions LLC, which is a for profit company focusing on software applications in the oncology workflow, quality assurance, and safety. Dr. Sridhar has no relevant conflict of interest.

REFERENCES